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THE GROWTH OF THE WORLD
AND OF ITS INHABITANTS

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THE GROWTH OF THE WORLD

AND OF

ITS INHABITANTS

by

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" To assume that the evidence of the beginning or end of so vast a scheme lies within the reach of our philosophical enquiries, or even of our speculation, appears to be inconsistent with a just estimate of the relations which subsist between the finite powers of man and the attributes of an Infinite and Eternal Being."

SIR CHARLES LYELL,
Principles of Geology
(concluding sentence).

PREFACE

IN writing this book the author has had in mind not only those whose special interest is in the Nature Sciences, but also those whose studies lie in other directions. He hopes that the former will find here a framework of ideas into which they may fit the multitude of facts with which they will have to deal: and that the latter will find a sufficient number of facts to enable them to grasp both the point of view of the Nature student and also the ruling ideas of the Nature Sciences. He feels confident that they will find in these ideas much that will illuminate their own studies.

H.H.S.

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ADDITIONAL READING

For those who wish to extend their knowledge further upon the subject matter of this book the following list will be helpful.

BOOKS RELATING TO PART I.

Principles of Geology (Lyell) may often be picked up second-hand. It is a great classic and is very readable. Parts are, of course, now out of date, but this defect can be rectified by reading the more modern books mentioned below :

Open-Air Studies in Geology (Cole), *Existing Glaciers* (Hobbs), *Earth Features and Their Meaning* (Hobbs), *The Scientific Study of Scenery* (Marr), *The Scenery of England* (Lubbock), *The Scenery of Scotland* (Geikie), *The World's Minerals* (Spencer).

The following deal with the earliest phases of earth history :

The Origin of the Earth (Chamberlin), *The Physical History of the Earth* (Joly).

The following deal with the later phases of earth history :

Geology for Beginners (Watts), *An Introduction to Stratigraphy* (Stamp), *A Textbook of Geology* (Rastall and Lake), *Origin of Oceans and Continents* (Wegener), *Meteorology* (D'Alembert).

BOOKS RELATING TO PART II.

General works :

The Science of Life (Thompson), *Origin and Evolution of Life* (Osborn), *Organic Evolution* (Lull), *Outlines of Palæontology* (Swinnerton).

Special works :

Origin of Species (Darwin), *Heredity and Variation* (Thomson), *Mendelism* (Punnett), *Men of the Old Stone Age* (Osborn), *Ancient Hunters* (Sollas), *The Antiquity of Man* (Keith), *Prehistory* (Burkitt).

A number of excellent books upon specific topics will be found in the " Home University Series " and Cambridge Science Manuals.

PART I

THE GROWTH OF THE PHYSICAL
WORLD

CHAPTER I

THE IDEA OF GROWTH

GROWTH is not merely increase in size. The seed falls to the ground, it springs up and grows, "first the blade, then the ear, then the full corn in the ear." At each stage something new emerges, but does not entirely replace all that has been before. Relics of the early stages linger on alongside of the latest additions, the shrivelled blade and dry stalk are still there even when the full corn has swelled out the ear. Thus it comes about that the last state is also the most complex. So is it with the World, for it too has grown, and fragmentary records of its past history lie all around awaiting the discovery of the key to their interpretation.

Things in Nature around may be classed into two great divisions, viz., the living and the dead. A bird settling on a rock, that is a symbol of Nature as a whole. The bird is here for a moment and is gone again, but the rock remains fixed and unmoved. The bird has wings with which to fly ; eyes to see ; and ears to hear. The rock has no such organs, its parts are all alike, merely miniatures of the whole. The bird has organs or parts that are adapted to the performance of certain functions, the rock, on the contrary, has no organs. The former

is, therefore, described as being organic ; the latter, inorganic.

The bird lays eggs and hatches out young. The parent dies and the young in their turn mature and reproduce their kind. So through the ages there has existed a long chain of short-lived organisms. It is not so in the physical or inorganic world. A pebble upon the beach of some primeval sea, if it is not ground to powder by the forces of Nature, maintains its identity for æons. It may be buried in the floor of the sea, and become part of some mass of rock. From this it may, after long ages, be liberated and rolled along the bed of some present-day brook. Despite the vicissitudes through which it passes, it remains the same pebble, made up of precisely the same particles as when the world was young.

Living things are conditioned in their existence by the inorganic realm : thus a fish must live in water ; the rabbit cannot burrow in granite. On the other hand living things take the resources of the inorganic world and use them for their own ends. Thus the plant draws water and food material from the rock and soil and gathers up its energy from the sunshine. The bird uses the forces of the wind for soaring up to the sky. This aspect of the organic world is pre-eminently characteristic of man, for he alone has a conscious understanding of the forces of Nature, and of the ways in which she hides her resources. He is able, therefore, to direct his energies towards exploiting these with the minimum of effort and of time.

Nevertheless man is still a child of Nature, whether

THE IDEA OF GROWTH

he lives a solitary life in the wilds or crowds with his fellows in great cities. It is only as he discovers Nature's ways of working, and acts in accordance with them, that he can direct his energies aright for overcoming obstacles in the path of his progress, or wresting a livelihood where his forefathers would have died of starvation or of thirst.

The world, however, is not only the home of man ; it is also his birthplace. The living things around him are not merely his companions, they are also his relatives, produced by the same processes, subjected to the same dominating physical conditions and to the same laws of life. When he understands these he understands himself better, and this wider understanding enables him, yet more efficiently, to direct his activities towards his own well-being.

The following pages are but a skimming flight over the great ocean of enquiry into the processes of Nature and their relation to man and his activities.

CHAPTER II

OLD VIEWS OF NATURE

THE idea that the Earth has had a past history which may be unravelled, is one which has grown. Only a century or more ago the prevailing attitude towards Nature was that of a little child who takes ordinary things for granted, and extraordinary things as the work of fairies. For example, within the limits of a half holiday ramble from Nottingham is the Hemlock Stone, a curious unshapely column of rock standing up in the midst of one of the grassy slopes which flank the Bramcote Hills. It strikes the eye of all who pass, and the question is invariably asked—"How did it get there?" The explanation that was current in the days of Queen Elizabeth ascribed it to Satan. One night he was busy with his wicked works in Derbyshire, and for a while success attended his efforts. That night the Prior of Lenton tossed about upon his bed unable to sleep, for he was strangely aware that ill deeds were being done not far away. Presently he arose and spent the hours of darkness in prayer. Satan, feeling that his activities were receiving a strong check, paused to consider whence it came, and then exclaimed, "It is the Prior of Lenton at prayer." He thereupon took a great rock and hurled it at the Priory, intending to

OLD VIEWS OF NATURE

crush it. He missed his aim, and the rock fell on Bramcote Hills, and is there to this day. Our forefathers listened, crossed themselves, and believed. To-day, such stories are received with incredulous smiles. How has this change of attitude been brought about? That question must now be considered.

For many centuries curious and observant men have found fossils buried in the solid rock. Some of these bore a striking likeness to the shells of creatures which live in the sea, or to the bones of animals which live upon the land to-day. Various explanations were given, as, for example, that fossils were "formed by tumultuous movements of terrestrial exhalations"; or that the "devil made them and put them in the rocks to lead men from the knowledge of or belief in the scriptures," or again that "when the animals were created from the dust of the earth, many were started but never finished," and these became fossils.

Nevertheless, some men were not content with such explanations. They were men who collected and studied these stones themselves, and they came to the conclusion that fossils were the actual remains of animals that once lived upon the face of the earth. In due time most thinking people came to accept this as the true explanation; especially when they found that they could dovetail it into their previous views by assuming that these were the animals that were slain in the deluge.

To the few who collected fossils, and studied the rocks in the quarries and cliffs, other facts became known which could not be so easily dovetailed into old beliefs.

THE GROWTH OF THE WORLD

They found that the rocks which contained fossils lay one on top of another in layers or strata, and that fossils were just as abundant in the bottom-most as in the top-most of these. It was easy to believe that those fossils which lay near the surface were the remains of creatures that perished in the deluge. But this explanation could hardly be applied to those bones and shells which were embedded in the solid rock of the more deeply situated layers.

Those observers who travelled abroad and gazed upon the Alpine mountains saw similar layers of rocks inextricably broken, bent and twisted. Their imaginations played around this strange sight, and they sought to fit the facts thus learned into their earlier views. Here, it seemed, was evidence for something more than a mere deluge. They pictured to themselves a time of great catastrophe, when mighty earthquakes shook the world and rent its crust, when Titanic forces crumpled the rocks as a man crumples a piece of paper, when volcanoes burst forth everywhere and filled the air with dense clouds of steam from which the rain fell in overwhelming torrents and, joining the waters of the sea, drowned the earth in universal deluge. Thus all living creatures were destroyed, the fishes of the sea as well as the inhabitants of the land. Eventually the tumult ceased, "the fountains also of the deep and the windows of heaven were stopped, and the rain from heaven was restrained." The waters stood still, the mud and sand churned up by the riot and wrack settled rapidly in layers, and buried the remains of the creatures that had perished. The floods returned from off the land

and, as they flowed away, scooped out the valleys and left the hills which now beautify the land. Then the creative fiat was uttered, "the earth put forth grass and herb yielding seed, fruit trees bearing fruit, living creatures, cattle, creeping things and beasts of the field."

Thus there grew up in the minds even of scientific men the view that the sequence of events in the past history of the earth was as follows :—First a period of calm and quiet like the present, then a period of catastrophe when all forms of life and surface features of the land were obliterated ; this was succeeded by a new creation and the establishment of the " present order."

Gradually, however, there came into prominence other facts which did not fit into this scheme of events. Those who were not content to gain their information from second-hand sources, but went out into the quarries and along the sea cliffs, came occasionally upon some such scene as this :—a cliff in which the rocks at the bottom were crumpled and folded, half-way up the cliff the crumples ceased at a clearly defined line as sharply as though the tops of the folds had been cut off by a knife ; above this line the rocks lay flat and exhibited no sign of crumpling. At first sight this seemed an excellent proof of the truth of the theory just propounded. The lower rocks had evidently been crumpled during the catastrophe, and the upper ones had been laid down during the flood. The presence of fossils in the lower rocks, however, raised a difficulty. It was easy to see that the fossils found in the upper rocks were the remains of creatures slain in the deluge. But here

were rocks which must have existed before the catastrophe happened, the fossils they contained therefore could only be taken as evidence of a yet earlier deluge. Further investigations in the field revealed similar evidence that this succession of events, a period of calm, of catastrophe and then a new creation, had happened not once, nor twice, but many times. Such then was the generally accepted view of the earth's history at the opening of the nineteenth century.

CHAPTER III

THE GROWTH OF MODERN VIEWS

A LITTLE more than a century ago there was at Oxford University a student called Charles Lyell. Among his legal and other studies he included Geology, and so he attended courses of lectures by the celebrated Professor Buckland, and heard the facts and theories discussed in the last chapter propounded. As a student he spent his holidays in tramping the length and breadth of Scotland. One day he was watching some workpeople draining a little lake on his father's estate, and was surprised to find that a layer of limestone, which was not present when the lake had been similarly cleaned some years before, lay upon the floor. This stone, which had obviously been formed during the interval, was as hard as any rock, and consisted largely of shells identical with those of the animals still living in the water. Thus the startling fact was forced upon his attention that fossils, and the rock which contained them, were being formed in the "present age" without either convulsions or floods, but quietly and slowly. The idea rapidly dawned upon his mind that perhaps there were forces and processes in Nature to-day, working quietly and slowly, which in course of time could do all the work which existing opinion ascribed to catastrophic agency.

Lyell preached, and acted up to his preaching, that travelling was meat and drink to the geologist. In spite of the difficulties which confronted the traveller in pre-railway days, he became familiar with most of the countries in Europe, and visited North America four times. In all his wanderings he observed Nature and studied her ways of working. The results of his investigations were summed up in a delightful and readable book, *The Principles of Geology*, first published in 1830, but subsequently revised and enlarged. This work laid the foundations of Modern Geology, and opened up lines of thought and enquiry which have borne fruit in many other branches of knowledge. A few illustrations drawn from the vast multitude of his observations must suffice to indicate the trend of his teaching.

In Georgia he found that, owing to the clearing away of the forests by the settlers, the rain, when it fell, collected more quickly than before into the streams which, therefore, swelled with greater rapidity into torrents. He saw for himself one little valley fifty-five feet deep and eighty feet wide, which had been excavated by these enlarged torrents in the course of only twenty years.

Similar, though perhaps less striking, facts may be seen by anyone. Even in the city a heavy downpour of rain will wash all the grime and mud off a dirty street. In the country the water which falls in the form of rain is as clear as crystal, but when it has been flowing across the fields, and along the runnels, it is discoloured with mud washed from the soil. Collected into a stream, it gains in power, it rolls pebbles and stones along in

endless procession. As it does so it wears and deepens its bed, it undercuts its banks, which then collapse and fall in. Meanwhile, both in the fields and in the river banks, the frost breaks up and loosens the soil, and the rain washes this also into the stream. Thus, as the bed of the stream deepens, its channel becomes widened by the action of rain and frost into a broad open valley. The ground left standing up between the valleys forms the hills.

At Reculver, on the north coast of Kent, Lyell found a church standing on the edge of a cliff overlooking the sea. A strange place to build a church ; but historical records proved that, when the church was erected in the days of Henry VIII., it was not less than one mile away from the shore ; and an old picture, dated 1781, showed buildings and fields still intervening between the church and the sea. Here, then, was irrefragable evidence that, in the present order of things, the sea was gradually wearing the land away. The waves, as they break at the base of the cliff, batter it with shingle and stones. By so doing they undercut the cliff until at last the overhanging portion, being unsupported, collapses and falls into the sea. Thus does the process of destruction of the land go on unceasingly.

The physical processes in Nature are not, however, wholly given over to works of destruction. The mud and sand that are carried along by rivers and streams, eventually reach the sea and, together with the *débris* produced by the destruction of the cliffs, are transported by undercurrents and are spread out in successive sheets upon the sea floor. First of all the shingle and gravel

come to rest near the shore. Beyond that the sand settles down. Further out still in the deeper and quieter water, the mud gradually sinks in depths of six hundred or even one thousand feet. Thus the waste, produced by the destructive processes which work unceasingly both at the surface and at the margins of the land, is spread out and piled up, layer upon layer, upon the floor of the sea.

During the eighteenth century there lived in the city of Stockholm a scientist called Celsius. Standing one day upon the beach talking to some fishermen, he learned that certain rocks which he could see jutting up out of the water were, within the memory of men still living, once hidden from view beneath the surface. The startling question was thus suggested to his mind—was the sea floor rising? To put the matter to the test he went out in a boat one perfectly calm day and chiselled a mark upon the rock at sea level. A century later, in 1831, Lyell visited Stockholm, and, examining the marks, found that they stood two and half feet above the level of the water. Evidently the sea floor was slowly rising. He then searched for further evidence, and found it in the form of beds of shellfish at various levels on the mainland up to a height of some hundreds of feet above the sea. These and many other facts convinced him that this upward movement both of land and sea floor had been going on for centuries.

So, then, the boundary between sea and land is not fixed. When such a new idea as this becomes established in the mind, then the eyes are opened to behold evidence upon every shore, evidence that shows not

only that in some places the land is rising and the sea retiring, but also that, in other places, the land is sinking, and the sea is encroaching. Thus, for example, at many points, even along the English coast, the stumps of trees may be seen, at very low tide, projecting from the beach. The roots of these may be seen spreading out at the base of each stump in such a way as to show that the trees grew just where their stumps now stand. When they were alive and waving their foliage in the breeze this ground, now submerged even at normal low tide, must have stood well above sea level. The fact that lumps of peat, and the bones of deer and other land animals, are occasionally brought up by fishing dredges from the floor of the North Sea shows that at one time part of it also was dry land.

Thus the surface of the earth, so far from being *terra firma*, is in a state of instability, rising here, sinking yonder. At one place the deposits of sand and mud, which have been laid down upon the sea floor, together with the shells which were buried in them, are being raised to form the rocks and the land. At another place the peat bogs and the forested plains are being silently submerged in the sea and buried beneath marine deposits.

It was by an overwhelming multitude of such facts and observations as these that Sir Charles Lyell established the principle, that the processes we see quietly at work in Nature to-day are competent to bring about, in the course of time, those great changes which had been previously ascribed to forces that worked actively only at wide intervals and with catastrophic vigour.

The idea that the era in which we live is one of unchanging calm was thus completely demolished. Nevertheless, there still remained some awkward facts, based upon the study of the rocks in the field, and of fossils in the rocks, which seemed to indicate that there had been periods of catastrophe and new creation. Sir Charles Lyell therefore gave his attention to a yet more detailed study of both rocks and fossils. During his travels he studied under the greatest specialists in the Science of Shells or Conchology. He also examined all the collections he could find, and thus gained an unrivalled knowledge of fossil remains. He then turned his attention to the shellfish which live in the Mediterranean Sea to-day, and to the fossil shells which are to be found in the rocks of the adjoining lands.

In order to understand the discoveries that resulted from all these very careful enquiries, let us assume that each letter of the alphabet represents a distinct kind of fossil shell (Fig. 1 a). Let A, B, C, D, be shells found living in the sea to-day. According to the catastrophic theory these were all newly created at the opening of the present era. The shells buried in the layers of rock which make up the adjoining land are the remains of creatures which lived in the previous period of calm and were destroyed during the last catastrophe. They should, therefore, be quite different from those living to-day, and may be represented by E, F, G, H. The early investigators had, in fact, collected from the rocks and found that the shells they contained differed to a marked degree. They had not, however, collected and observed with as much care as did Sir Charles Lyell. He

THE GROWTH OF MODERN VIEWS

collected fossils from the rocks, but he kept those found in each layer separate from one another, and thus was able to detect a gradual change in the grouping of kinds. As he passed from the lower to the higher layers of rock, he found that some kinds disappeared and new ones came in. Instead of there being two clearly cut and well-defined groups, such as E, F, G, H, on the one

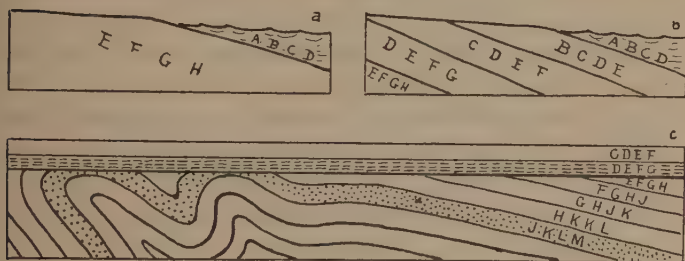


FIG. 1.—Three diagrams showing the general relationships of layers of rock to one another below the ground.

a illustrates the old idea that the fossils (E, F, G, H) in the rocks were quite different from the creatures (A, B, C, D) that live in the sea to-day.

b illustrates the modern idea that whilst the fossils in the oldest layers are very different from creatures living in the sea to-day, the difference becomes less and less marked in the successive layers of later rocks, until in the latest rocks it has almost disappeared.

c shows a lower or older set of rocks in which the layers have remained flat in one area, but have been crumpled and partly worn away in another. An upper, younger set of rocks has been laid on top of the older. Where the older rocks have not been folded and worn away there is a gradual unbroken series of changes in the fossils from one set of rocks to the other.

hand, and A, B, C, D, on the other, there was a succession of overlapping groups (Fig. 1 b), thus E, F, G, H, in the bottom or oldest layer, D, E, F, G, in the next, and

C, D, E, F, and B, C, D, E, in succeeding layers, to A, B, C, D, in the present seas. Thus careful collecting from the rocks, followed by painstaking identification and cataloguing of the fossils, proved that the grouping of life forms in the sea had not changed suddenly but gradually with the passage of time.

It should be noticed that both the catastrophists and Sir Charles Lyell made one great and fundamental assumption, viz., that under normal circumstances where there are two layers of rock lying one on top of the other, the one that is underneath must have been laid down first, and is, therefore, the older. The one that is on top must have been laid down last, and is, therefore, the younger. This assumption is so obviously true that it needs only to be mentioned in order to receive approval. The principle involved is referred to as the Law of Superposition, and has furnished the foundation upon which all modern knowledge relating to the growth of the world has been built.

When layers of rock lie flat one on top of another, like a pile of books, they are said to be conformable to one another. As described in the previous chapter, a group of flat rocks may rest upon the edges of crumpled rocks that have had the crests of their crumples worn away. These rocks are described as being unconformable to one another (Fig. 1 c left). In such cases the fossils in the lower or crumpled rocks were found to be as distinct from those found in the upper rocks as J, K, L, M, is from D, E, F, G. Here, then, it seemed, was complete and indisputable evidence of sudden and

catastrophic change. Sir Charles Lyell gave careful attention to this type of fact. He confirmed the observation that such breaks occurred in some places, but instead of concentrating his attention only upon the spot where the break occurred, he traced the layers of rock from place to place, and over extended areas, with very fruitful results. He found that in other places (Fig. 1 c right) the rocks containing fossils J, K, L, M, were not so crumpled, and that occasionally new layers occurred between them and the upper uncrumpled series. In these new layers the fossils differed slightly, thus H, J, K, L. In regions yet further afield the older rocks were flat and uncrumpled. Moreover, a complete succession of layers was found in which the fossils of the group J, K, L, M, gradually disappeared and those of group E, F, G, H, appeared. He concluded, therefore, that the forces which crumpled the lower rocks had not been world-wide and catastrophic in their action, but that whilst they were being exerted in one region of the earth's surface, in all other regions the forces and processes, already discussed above, were acting as quietly and effectively as at the present day.

Some explanation is necessary of the conditions under which work upon rocks in the field is carried on. A glimpse at the landscape suffices to show that the rocks are almost completely hidden from view by a covering of soil and vegetation, of swamps and forests, of lakes and seas. The rocks themselves are to be seen only at widely separated places in sea cliffs and quarries, in road cuttings and trenches. The task for the geologist is to trace a rock which he has seen in a cliff or road cutting

across the landscape. This he is able to do because the successive layers of rock differ from one another in their ability to resist the wearing action of rain and frost. Some yield easily and so are worn down quickly to low levels. Others yield only slowly, and so are not worn down so quickly, their course across the landscape is therefore marked by ranges of hills, lofty or subdued as the case may be. To the trained eye every change of slope, every hollow and curve, every peculiarity of soil and of vegetation reveals something concerning the rock which forms the hidden foundation of the countryside.

The tracing of the outcrop of a layer of rock is a long and tedious process. In some portions of the earth's surface, as, for example, those obscured by seas and lakes, it cannot be done. Nevertheless it is possible to correlate the rocks on one side of an unexplored region with those on another by means of the fossils they contain, for if the fossil group in the one closely resembles that of the other, it is evident that the rocks in question must have been formed at about the same time in the earth's history.

The working out of the order in which the layers of rocks and groups of fossils succeeded one another opened out great new possibilities. It did for the ages what the clock face does for a day, it provided a concrete basis for visualising the passage of time, and for dating the multitude of events which happened upon the earth before mankind discovered the art of making written records. In short, it made the reconstruction of the history of the world a possibility.

The publication of the *Principles of Geology* completed the revolution in the attitude of thinking men and women towards the physical universe which had been going on for more than a century. The mediæval now gave place to the modern conception of the world. No longer was it regarded as the product of forces and methods of working beyond human ken, but of processes still at work to-day and open to human investigation.

CHAPTER IV

ROCK TYPES AND THEIR ORIGIN

THE farmer whose land has a heavy clay soil likes to plough his fields in the autumn. Walking across such a ploughed field is proverbially heavy going by reason of the long ridges of large, irregular clods. In the springtime, however, there is a remarkable difference, especially if the winter has been a severe one, for the great clods have disappeared and the ground is covered with a fine, powdery soil. During the intervening months the rain has soaked into the stiff clay, and the frost has frozen the water which has penetrated. As it froze, the water expanded and forced the particles of clay asunder, so that when the thaw came they lay loose upon the ground. By the constant repetition of this process, all the ploughed-up clods became reduced to powder.

In precisely the same way, but more slowly, the rain and frost break up our brick walls, and shatter the rocks in the hillsides and on the mountain slopes.

In regions such as the Sahara and Central Australia, where there is very little rain, the same result is accomplished in a slightly different way. During the daytime the brilliant sunshine causes the surfaces of the rocks to become highly heated and to expand. At night the

heat radiates away rapidly and the rock cools and contracts. This alternate expansion and contraction of the surface of the rock causes it to crack and break away from the main mass. Thus the great changes of temperature which take place from day to day and season to season shatter the rocks, and pulverise the stones, as effectively as hot water from a boiling kettle cracks and breaks the household crockery.

By these, and other less obvious processes, the rocks which make up the land are everywhere being gradually shattered and reduced to powder. The fine material thus formed is washed down the hillsides by rain, or, in arid regions, is transported elsewhere by the wind. For a time it lodges on the gentler slopes and in the valleys as soil; but eventually it finds its way into the rivers and streams, and is carried down to the sea, or into those vast areas of low-lying ground which occupy the centres of the continents of Australia and Eurasia. There it is deposited in broad, thin sheets. It matters not whether this basin of deposition be the sea or an inland depression, the coarser, heavier deposits are dropped first in the form of shingle and gravel along the margin of the basin. The finer or sandy material is laid down next. The fine dust is carried furthest afield and settles down eventually in the centre of the basin or in the deeper waters of the sea. The sediment that is thus laid down during any given period of time forms an extensive sheet which varies in composition from place to place, consisting here of gravel, there of sand, yonder of dust.

As sheet upon sheet is laid down, the basin becomes gradually filled and the sea shallower. Sometimes those

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portions of the sea where sediment is accumulating become completely silted up. If, however, the sea floor be sinking, the process of silting is counterbalanced by the downward movement (Fig. 2 a to c). The depth of the water then remains comparatively constant, but the thickness of accumulated sediment continually increases, and may amount to hundreds or even thousands of feet.

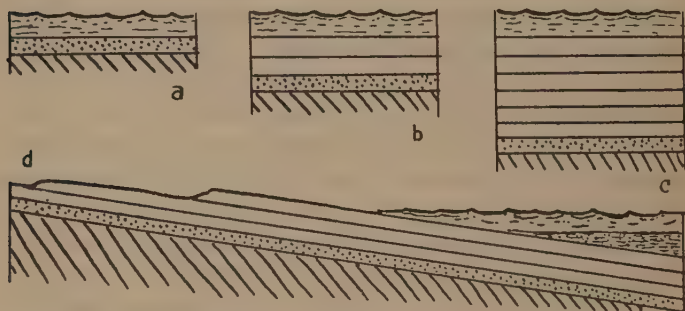


FIG. 2.—Diagrams illustrating the way in which great thicknesses of rock accumulate in shallow water (a, b, c) and how they come to form extensive areas of dry land (d).

Sooner or later an upward movement takes place which lifts the deposits above sea level to form land. They then become compacted into rock, the gravels become conglomerate, the sands become sandstone, and the dust or mud becomes clay, shale and marl.

Whilst the sea floor is acting as a receptacle for these various kinds of sediments, it also provides a home for

multitudes of lowly animals, many of which make shells of lime. When they die these shells are buried in the sediment and become fossils. Here and there are patches of the sea where the water is clear, and very little sand or mud is being deposited. In such places only the shells and skeletons of marine animals accumulate. When these become compacted into rock they become limestone.

Rocks formed in the ways just described are called *sedimentary rocks*. Owing to their mode of origin they are made up of sheets or layers lying one above the other. For this reason they are frequently referred to as the *stratified rocks*.

Each layer or stratum varies greatly in character from place to place. Thus in rocks of marine origin that portion which was formed near the land is thick, and consists of coarser material of sand or even pebbles. That formed far out to sea is thin and finely textured. The study of such features serves to guide the investigator to the positions of primeval shore lines or of deeper seas.

The slope of the sea floor is so gentle that it is practically horizontal; so likewise are all the strata that are laid down upon it. If, when uplift takes place, the whole area rises uniformly, the strata will remain horizontal. If, however, it rises more rapidly in one part than in another, the layers will become tilted (Fig. 2 d). The direction in which it tilts is called the *dip*, and the direction of maximum tilt is the direction of *true dip*. Upon a tilted surface there may be drawn lines that are level or horizontal. Such lines

are called lines of *strike*, and they are invariably at right angles to the direction of true dip.

In quarries and cliffs the rocks may be seen lying sometimes horizontally, sometimes dipping. Thus there is presented for interpretation a record of the movements of uplift and depression that have taken place in past ages in the regions where the rocks occur now.

In addition to being tilted, layers of rock may be bent into folds (Fig. 10). A bend upwards is called an upfold or *anticline*, a bend downwards is called a downfold, or *syncline*. The character of the folds varies greatly from place to place, sometimes they are merely low, broad undulations with only gentle dips on either side. Sometimes the fold is narrow and high, with steep dips on either side. Elsewhere the folds are still narrower, and have fallen over to one side, thus forming what is called an overfold. There are yet further degrees of folding, which will be dealt with later. The study of the degrees and systems of folding likewise throws much light upon those great episodes in the earth's history called periods of mountain building.

Another type of rock, quite different in character from that just considered, originates in association with volcanic phenomena. A volcano in activity is one of the most impressive scenes that the eye of man can witness. Here are manifested forces which work with all the noise and commotion of a catastrophe. Nevertheless the individual volcano, mighty as it seems to human sight, is but a pinpoint on the earth's surface. It is a merely local expression of great subterranean

reservoirs of energy, while the uproar is of no greater significance than the splash of a wave upon the beach as compared with the majestic movements of the ocean as a whole.

The processes of nature hitherto considered have been concerned with the transference of material horizontally, from one part of the earth's surface to another. The outstanding peculiarity of a volcano is that by its means material is transferred vertically, from below the ground to the surface. This material, popularly called lava, is a highly heated liquid which, when it cools, solidifies and forms a rock. A rock thus formed is described as *igneous* to distinguish it from rocks of sedimentary origin.

It is not correct to say that such a rock has been formed from molten material. An illustration is necessary in order to make this clear. Ordinary table salt is a solid, and so is ice. If, however, the two be mixed together they react upon one another in such a way as to form a liquid even though no heat is applied. This mixture remains liquid at temperatures far below those at which ice and salt, taken separately, normally melt. Similarly lava consists of a mixture of substances. Though its temperature is high it remains liquid still at temperatures far below those at which the substances taken individually will melt. Such a liquid is called a *magma*. It is not molten rock, it is essentially a mutual solution of mineral substances.

In course of time a volcano becomes extinct (Fig. 3 v). It ceases to pile up lava and the débris from its explosions. From this time onwards, rain and frost, running water and changes of temperature, wear it

away until the very foundations of sedimentary rock upon which the volcanic mountain was built are exposed, and the fissure or pipe up which the magma welled is brought to view. In due course the layers of rock are also stripped away one by one. From time to time, sheets of igneous rock formed from magma that never reached the surface become uncovered. Sometimes

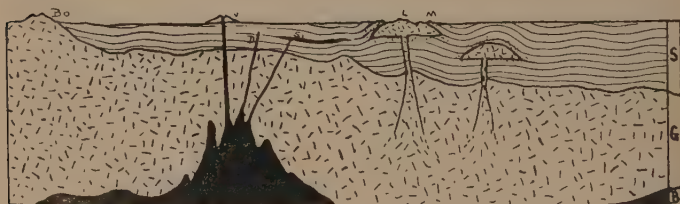


FIG. 3.—Diagram showing the probable relationships of different masses of igneous rock to one another. S sedimentary rocks lying upon a foundation of granite (G), which makes up the main mass of a continent. B is part of the basalt layer which underlies the granite. Bo is a boss of granite, a small portion of the continental mass which has become exposed at the surface. L a small mass of granite which came up from the continental foundation in a liquid state and found a resting place between the beds of sedimentary rocks. M is the zone of sedimentary rocks which have been metamorphosed by the intense heat of the liquid rock. V a volcano in which the liquid basalt has found a way to the surface. D (dike), Si (Sill), here the liquid did not reach the surface.

such a sheet lies between the layers ; it is then called a *sill* (Fig. 3 Si). At other times it cuts vertically across the layers, and is then known as a *dike* (Fig. 3 D).

With continued uplift and denudation, a total thickness of some miles of deeper and yet deeper rocks are removed until great masses of rock (Fig. 3 L), formed

by the cooling and consolidation of reservoirs of magma, may be revealed. Compared with these masses, some of which may be scores or even hundreds of miles in extent, the volcano sinks into insignificance.

The igneous rocks which were formed from magma that was poured out on the surface, and that which was injected into the rocks beneath are called extrusions and intrusions respectively. The latter are described as deeply seated or surface intrusions according to the original depth of the rock into which they were injected.

Naturally the magma which was poured out as lava

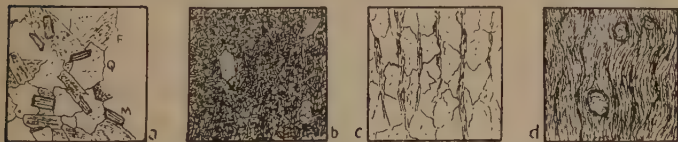


FIG. 4.—Drawings made from thin slices of different kinds of rocks as seen under the microscope. a granite, b basalt, c gneiss, d schist. In a, F=felspar, Q=quartz, M=mica.

upon the surface was cooled much more quickly than that which remained enclosed by the rocks beneath. The intrusions also cooled and consolidated at different rates, those near the surface more rapidly, those deep down very, very slowly.

These differences in the rate of cooling of the magma under the varying conditions gave rise to a striking difference in the texture of the rock that was ultimately produced. A brief description of the characteristics of several typical igneous rocks will make this clear.

Take first a piece of coarse *granite* (Fig. 4). If this

has one surface polished, the details can be made out more easily. A close inspection with the naked eye or with a pocket lens will show that the rock is not homogeneous. Some small portions of it seem to be made up of pieces of transparent glass. Others of a dull white or pink material, others again consist of shining flakes. Each of these is a separate mineral. The first is *Quartz*, which consists only of silica or silicon dioxide. The second is *Felspar*, which consists of silica combined chemically with either potash, soda or lime. The third is *Mica*, which also contains silica, but in this case it is combined with magnesia and iron oxide.

Sometimes a piece of granite has a cavity, from the sides of which the minerals may be seen projecting. Each mineral is then seen to have a quite definite geometrical form with flat surfaces. Such a mineral form is called a *crystal*. A quartz crystal is a six-sided prism with a six-faced pyramid at the end. The mica crystal is a short six-sided prism with flat ends. The felspar crystal cannot be so easily described. The crystal form assumed is a very characteristic feature of each mineral, and is associated with the arrangement of the ultimate particles of which the mineral consists. Other curious optical properties revealed by the examination of thin slices under the microscope are also closely linked up with the crystalline form and its ultimate structure. If a crystal be smashed with a hammer each broken fragment exhibits these same properties. Although they no longer possess the form of a crystal, these fragments are still crystalline. In

addition to these physical properties each mineral has a nearly definite chemical composition.

A piece of granite has no such clearly defined properties. It consists of several minerals, and is therefore said to be a *rock*.

As a second example of an igneous rock *basalt* (Fig. 4) may be taken. It is quite as abundant as granite, but is not so familiar because it is not used except for mending roads. It is a black rock. When examined in thin slices under the microscope it is seen to consist largely of crystals, but these are so small that they cannot be seen by the naked eye or even with the help of a pocket lens. Unlike granite it appears as a finely grained homogeneous rock.

This difference in texture between the two rocks is due to the conditions under which they cooled from the liquid state. The granite was formed from a deeply seated magmatic reservoir, which because it had such a thick covering of sedimentary rocks cooled exceedingly slowly and therefore remained liquid a long time. The ultimate particles of each mineral were, therefore, able to congregate gradually around a few widely spaced centres of crystallisation, and as they congregated the crystals grew to considerable sizes, and a coarse-grained granite was the result.

The basalt was formed by the consolidation of a lava flow. The rate of cooling was much more rapid than in the case of the granite. The crystalline particles, therefore, congregated round many closely spaced centres and the resulting crystals were, therefore, both small and numerous.

Occasionally the process of consolidation is so rapid that the magma sets solid before these processes of crystallisation have begun, and thus forms a natural glass of which *obsidian* is the best example.

Besides exhibiting all grades of texture from coarsely-grained through finely-grained to glassy, igneous rocks differ from one another also in the groupings of minerals they contain. Thus one of the coarse-grained rocks consists of quartz, felspar and mica, a second of felspar and hornblende, a third of augite and olivine. Both texture and mineral composition have proved invaluable aids in the classification and identification of igneous rocks. Much importance is also attached to the relative proportions of the various chemical constituents that are present, but the chemical analysis of a rock is a long and tedious operation.

In addition to the sedimentary and igneous there is yet a third type of rock, the *metamorphic*. As its name implies, this is formed by the complete modification or disguising of the characters of the other types of rock. Brick and porcelain are, so to speak, artificial metamorphic rocks. What was once moist, soft, plastic clay has been changed by high temperature into something that is hard, dry and brittle. The clay has been metamorphosed.

Similar changes of an even more striking character may take place in Nature. Thus, for example, when a great reservoir of hot magma is injected into the midst of a mass of sedimentary rocks, the latter become highly heated. Those portions which adjoin (Fig. 5 M) the reservoir may be melted or even be absorbed into the

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magma. Some distance from the reservoir the sedimentary rocks will not be so highly heated. Further away still, no marked change of temperature will be experienced.

Here and there, when the igneous rocks formed from such masses are exposed to view, the effects of these differences of temperature upon the different kinds of sedimentary rock may be studied. Take, for example, a dark limestone that is teeming with fossils. As the granite is approached, the colour of the limestone

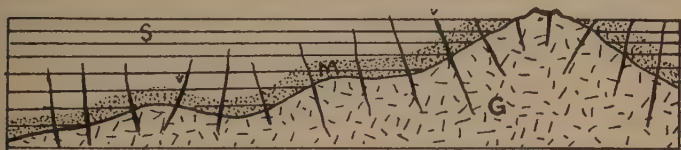


FIG. 5.—Diagram showing the relationship between mineral veins or lodes (v), and other kinds of rock such as S, sedimentary, M metamorphic, and G, igneous rocks.

becomes lighter, the fossils gradually lose their structure, and the material of which they consist merges into that of the mass of limestone which encloses them. At last in the immediate vicinity of the granite, the limestone becomes a pure white marble. Under the influence of prolonged exposure to high temperature and under the enormous pressure of great thicknesses of rock, the molecules of the lime, or calcium carbonate, which constitutes both the fossils and the rock, have become rearranged in that regular manner which is characteristic of crystals. A thin slice of marble when examined

under the microscope is seen to consist of a mosaic of those crystals of lime known as calcite. The character of the rock has therefore been completely changed. It has been metamorphosed from a fossiliferous limestone into a crystalline marble. Marble is, therefore, a metamorphic rock.

Sandstone that is similarly subjected to great heat and pressure may be likewise metamorphosed. If it be a sandstone that contains fragments of felspar and mica as well as of quartz, these grains lose all traces of exposure to the action of frost, rain, and running water. Without being actually melted they become completely recrystallised, with the result that a rock is formed which at first sight might easily be mistaken for a granite. Close examination, however, reveals the fact that the minerals are all squeezed out into more or less flattened flakes, having their planes of flattening all lying roughly parallel to one another. This structure imparts to the broken surface of the rock a streaked appearance not usually exhibited by a piece of granite. A metamorphic rock, having this coarsely crystalline but flaked or streaked structure is called a *gneiss* (Fig. 4). Gneisses may be either metamorphosed sandstones or metamorphosed granites.

In some cases it seems that high pressure, rather than high temperature, is the dominant metamorphosing agency. It has already been seen that layers of rock that were once flat may be folded by the application of lateral pressure, that is to say, pressure applied against their margins. At first only folding, like the sides of a concertina, results. As the pressure increases,

the folds become squeezed one against another, and no further folding can take place. With continued pressure other changes begin to take place. Thus, for example, in clays and shales the molecules which make up the small particles of the rock rearrange themselves so that these particles become thin plates placed at right angles to the direction of pressure. If at this stage pressure ceases, a rock will have been formed consisting of minute thin flakes having no regular relationship to the original bedding plane or plane of the strata. Such a rock often splits quite easily along the direction of these flattened particles into thin slabs called slates. Slate rocks may be regarded as incompletely metamorphosed clays or shales.

In more advanced stages of metamorphism the minute flakes grow and become mica. When this change is complete, the colour and texture of clay which was still evident in the slate vanishes and the whole rock is flaky and has the bright silvery sheen of mica. A metamorphic rock having this fine-grained flaky character is called a *schist* (Fig. 4). One which consists largely of mica is a mica schist, if of hornblende it is a hornblende schist.

Highly heated masses of magma are not the only sources of heat that produce metamorphic rock. Deep boring and deep mines reveal the fact that the temperature of the earth's crust rises with every increase of depth. Now it has already been seen that great masses of sediment may accumulate to a depth of ten or even twenty thousand feet. As this accumulation proceeds the bottommost layers are pushed down further and

further into the earth's crust. In addition to being subjected to the pressure of thousands of feet of superincumbent rock, they experience a gradual rise of temperature as the heat of the earth's interior is conducted into them. Eventually they reach temperatures comparable with those of the magmas, whose metamorphosing action upon the rocks which surround them have already been considered, with the result that these lowermost strata likewise become metamorphosed. In this case the action is on a vaster and grander scale. It is not merely confined to a narrow belt or aureole of country only two or three miles wide, such as that which may be seen around many of the granite masses even of our own country. On the contrary, it has produced those great areas of metamorphic rock which to-day make up more than half of Canada, and regions of comparable extent in all the continents.

CHAPTER V

THE NATURAL STORAGE OF ORES

THE earth's surface is made up mainly of four mineral substances—water, quartz, felspar, limestone. The first exceeds all others in extent and bulk, it not only fills the ocean basins but it pervades the cracks and pores of all the rocks. The second accounts for three quarters of the substance of igneous and metamorphic rocks, and a still larger proportion of the sandstone. Felspar, the next most common constituent of these rocks, produces, as the result of its decomposition, china clay or kaolin, which is the basis of all clays. Lime or calcium carbonate occurs in massive form as limestone. These four substances supply the bulky needs of civilised mankind, water, soil and building material.

There are, however, innumerable rarer minerals of great value for special purposes, which occur finely disseminated in the substance of these abundant rocks and minerals. Thus, for example, every ton of sea-water contains, on the average, two pennyworth of gold ; and every ton of granite three ounces of copper. If all the gold in the sea could be abstracted, the yield would be seventy-five thousand million tons—but the cost of extraction would greatly exceed the value of the gold itself. The amount of these rarer minerals is ample for

all human needs, but the cost of eliminating the common minerals renders them practically inaccessible. There are, however, processes at work in Nature which exert a sorting action that carries out this process of elimination, and produces local concentrations of valuable ores and minerals. Some of these may now be considered.

It has already been seen that, when a magma cools, the minerals which were dissolved in it crystallise out. This is done in an orderly fashion—the mica comes out first, then the felspar, and lastly the quartz. The same principle governs the crystallisation of the less common minerals also. Thus, for example, magnetite or magnetic iron ore appears even before the mica. Now the whole reservoir of magma does not cool and consolidate simultaneously. These changes naturally take place first of all in the outermost portions of the reservoir, where it is in contact with the surrounding rocks. From thence the change spreads gradually inwards. One result of all this is that minerals which crystallise out first tend to become concentrated along the outer margin of the magma, thus leaving those which crystallise out later to become more concentrated towards the centre.

Again a mineral such as magnetite that is rich in iron is heavier than others like quartz, which contain no iron. These heavier minerals therefore not only appear first but they tend to sink through the still liquid magma, and thus to become concentrated in its more deeply seated portions. These, and other processes and tendencies, which, as yet, are not fully understood, account for the existence of a number of very valuable stores of iron ore which are associated with large masses

of igneous rock. It must be remembered, however, that many masses of iron ore originate in other ways.

Whilst some concentrations of valuable minerals are thus associated with the early stages in the consolidation of magmas, others are closely linked up with the final phases. Lava is not the only material which issues forth from a volcano. Steam comes forth in such quantities as to form clouds of mountainous proportions and torrential downpours of rain. Steam continues to arise from the lava stream as it flows along; and if when the lava is cold and solid, it be broken, it will be found to contain innumerable little cavities formed by the bubbles of steam which did not escape. All this proves that water is present in large quantities diffused through the magma. Owing to the very high temperature, however, it is there only in the form of its constituent gases, hydrogen and oxygen, which are dissolved under pressure in the liquid, like the gas in ginger beer.

Other gases and fumes of various acids similarly dissolved in the magma issue forth from the crater and fissures of a volcano even when it is not in active eruption. These react upon one another as they come up from below, giving rise to solids such as sulphur and boric acid, which condense and accumulate upon the sides of the fissures. These, like the steam, are but final concentrations of useful materials which originally were diffused through the once liquid rock hidden away far down in the earth beneath.

Between the crystallisation of the felspar and quartz from the magma, and the deposition of these more volatile materials at the surface, there are many inter-

vening stages. What actually takes place deep down in the earth can never be known by direct observation, but more or less reliable inferences as to the sequence of events may be inferred from the careful examination of masses of igneous rock now exposed at the surface. As the more common minerals crystallised out they increased in size until they became jammed one against another and the rock became set. Nevertheless, there were numerous spaces in between these crystals which contained magma consisting of the minerals, and gases and vapours which still remained in solution. Meanwhile the outer more solid portions of the rock, as they became colder, shrunk and cracked. The rocks around them also shared in this cracking. Into these cracks the residual portions of the magma oozed, carrying with them, into these restricted passage-ways, in concentrated form, many substances which at first had been widely diffused through the magma.

The residual liquid consisted largely of silica, and sometimes contained concentrations of gold. When this cooled and consolidated in the cracks and fissures it formed those quartz reefs which in Australia and Alaska and other parts of the world have proved to be so productive of gold.

Up along some of these vertical subterranean passage-ways and shafts the vapours and gases poured, as from a chemical laboratory in chaos, steam, fumes of sulphurous, hydrochloric, hydrofluoric, and boric acids, vaporous compounds of tin, copper, arsenic, zinc, lead—all rolled upwards through the strata, cooling as they went, and reacting upon one another, with the result that

first one mineral and then another settled out in the solid state upon the sides of the fissures. This they did in a more or less orderly fashion, tin ore first in the deeper regions, then copper ore, then last and in the upper sections the ores of zinc and lead. The gases and fumes that remained either penetrated and altered the surrounding rocks, or escaped at the surface in the way that has already been described. Eventually all became cold, and the same processes, which have laid bare the foundations of volcanoes and the solidified magmatic reservoirs, also exposed the valuable mineral lodes and veins formed in these fissures for man to discover and exploit.

Whilst these reefs and veins were being exposed portions of them were destroyed and large quantities of the valuable mineral were scattered broadcast once more. Nevertheless the less perishable among them, the gold and the tin ore, were frequently gathered together in yet richer concentrations by the action of running water. Rivers and streams, descending from the hills, transported the *débris* formed by the destruction of the rocks to the lower ground, and deposited it there ; thus forming those flats which are so characteristic a feature of riverside lands. Such deposits are called alluvium. The strength of the river currents varies greatly from time to time according to the state of the river, but it is always sufficiently strong to carry the lighter *débris*, mud, or even sand, down to the sea. The coarser material and heavier minerals, such as gold and tin, on the other hand, tend to be left behind ; with the result that the alluvium becomes rich in these

valuable metals ; and forms what are called alluvial or placer deposits. These are so easily excavated that even primitive man with his crude tools could work them. Not until these have been exhausted does man turn his attention to the veins and reefs themselves.

The action of water just described is purely mechanical. Important as that is, chemical action of water is of even more importance. One or two examples of this may now be considered.

Iron is the commonest of the colouring materials which occur in Nature. The red colour of many sandstones and clays is due to the fact that a thin film of iron oxide or rust coats every grain. In this form, iron is, of course, much too scattered to be of any value. In Cumberland and other places, thick masses of these red rocks overlie layers of limestone. The water that falls upon the sandstone percolates downwards through it, and as it does so dissolves small quantities of the iron out of the rock. When this water reaches the limestone it begins to dissolve this also. Now for chemical reasons, the discussion of which is beyond the scope of this book, iron compounds will not remain in solution when lime is present, and so they come out as the lime goes into solution. Thus it comes about that in the limestone near its surface of contact with the red sandstone, iron ore is deposited and, with the lapse of time, accumulates in quantities sufficiently great to repay the miner for the labour of excavation and removal. The extensive ironstone fields which occur in Yorkshire, Lincolnshire and elsewhere have been brought into being by similar processes of concentration.

CHAPTER VI

THE EARTH'S INTERIOR

FROM the previous pages some knowledge has been gained of the rocks which appear at the earth's surface and of their mode of origin. Of necessity only those rocks have been discussed which constitute the land and, therefore, occupy but one-quarter of the surface of the globe. The remaining three-quarters are hidden from view by ocean waters and continental ice sheets, and are therefore inaccessible.

Limited as our knowledge is, therefore, of the material of the earth's surface, it is still more limited for the earth's interior. Direct observation is, in this case, made by means of borings and mines. These rarely penetrate to a greater depth than one mile, and therefore lie well within the range of the surface irregularities of the earth. From the greatest depth in the ocean to the crest of the loftiest mountain the vertical distance is twelve miles. Even this is very insignificant compared with the diameter of the earth as a whole, which is only a little less than eight thousand miles. Nevertheless, there are various other sources of information which throw light upon the constitution and condition of the more deeply seated rocks, and of the main mass of the earth's interior.

From the records of numerous borings and mines it has been proved that the temperature of the rocks increases with their depth at an average rate of 1° F. for every sixty feet. Assuming that this increase continues, then at a depth of only a few miles from the surface the temperature must be sufficiently high to melt even the most refractory rocks. It must not be assumed, however, that they are therefore in a liquid state. In all probability they are not, for the tremendous pressure exerted by the overlying rocks is sufficient to prevent the actual process of melting from taking place.

That such great temperatures do exist is further indicated by the highly heated lava that issues from volcanoes, and by the completely metamorphosed condition of rocks, now exposed at the surface, which must at one time have been buried at depths of many thousands of feet.

Other lines of evidence concerning the interior constitution of the earth are not geological but are derived from other branches of science. One of the most fascinating lines of enquiry has the plumb bob for its fundamental instrument of investigation. The weight at the end of the cord hangs down for the same reason that all other objects fall to the ground, viz., because the earth exerts an attractive influence, called the force of gravitation, upon them. In actual experiment this has been balanced against the attractive influence exerted by various mountain masses.

For the purposes of simple explanation assume that the earth is a perfect sphere (Fig. 6 a), with a quite

smooth surface. . The cord which holds the plumb bob in this case points exactly towards the centre of the earth. That is to say, the line of the cord is strictly vertical. Now place a mountain on the earth's surface near to the plummet (Fig. 6 b). By reason of its great mass it will exert such an attractive influence on the plumb bob as to pull the cord slightly out of the strictly vertical line. The greater the mountain is, the greater

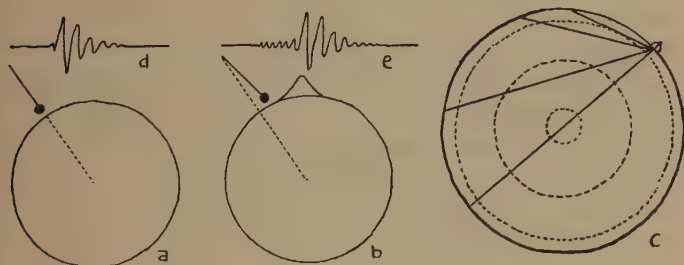


FIG. 6.—Diagrams illustrating two ways of gaining knowledge about the earth's interior.

a and b shows the way in which the attraction of the earth as a whole for a ball of lead may be compared with the attraction exerted by a mountain.

c shows how the waves sent through the earth from an earthquake centre pass through shallower or deeper portions of the earth's interior. d and e show the kind of record made by a special earthquake wave receiving apparatus according as the path pursued through the earth was a shallow or a deep one.

will be the displacement from the vertical. The amount of this displacement provides a basis from which it is possible to calculate the relative strength of the attractive forces exerted upon the bob by the earth and the mountain respectively. The sizes of the earth

and the mountain are known, and it is natural to suppose at first that the attractive forces would be directly proportional to these sizes. This is not the case. As a matter of fact the attraction exerted by the earth as a whole is twice as great in proportion to its size as is that of the mountain. This can only be due to the material, which makes up the interior of the earth, being denser than that of which the mountain consists. The rocks which make up the latter and the surface of the land are slightly more than two and a half times as dense as water. The density of the interior of the earth as a whole is, therefore, more than five times that of water.

When the plumb bob is set swinging it becomes a pendulum, and can then be used for discovering yet further facts about the earth. When the bob of the pendulum is pulled sideways it rises higher from the ground. Immediately it is released the force of the gravitation pulls it down to the lowest point that the cord will allow. The impetus of the swing, however, carries the bob past this point and sends it swinging up on the other side. Thus the bob continues to swing to and fro. With any increase in the force of gravitation the bob is drawn more rapidly towards its lowest point and consequently the rate of swinging, which may be measured by counting the number of swings per minute, increases. The pendulum is, therefore, a very delicate instrument for detecting variations in the strength of the force of gravitation. By its means it has been shown that this force is greater in the oceanic areas than over the continental masses ; a fact which indicates

THE EARTH'S INTERIOR

that the rocky materials which make up the continental masses are not so dense as those which form the floor of the oceans.

But perhaps the most fruitful source of evidence concerning the interior of the earth has been the study of earthquakes. When a great earthquake takes place the whole earth trembles. The first problem to be solved was how to record these. The chief difficulty lay in finding a penholder that did not tremble with the earth. The necessary conditions for securing this may be illustrated by means of a simple experiment. Tie a heavy weight to the end of a very long piece of strong, thin string, and let it hang from your hand. When the weight is quite still shake your hand vigorously and it will be found that the weight will remain unaffected for a long time. It would be equally unaffected if your hand were still but the floor upon which you stood were shaken by an earthquake. A weight suspended in this manner provides the stable penholder that is required. If the point of a pen, fastened to such a weight, rests lightly upon a piece of paper on the floor, then when the floor is shaken, the paper will move under the pen point and an irregular line will record the fact that an earthquake has taken place. With a properly constructed instrument, the paper is moved by clockwork slowly in one direction, day and night. As it does so the pen draws a straight line upon it. When an earth tremor comes the paper shakes and the movement is recorded as a series of crinkles in the straight line (Fig. 6 d, e).

When a great world-shaking earthquake takes place, the vibrations travel in all directions from the centre

of the disturbance ; some go round the earth, others through it (Fig. 6 c). The time of arrival, and strength of each is accurately recorded by the instrument. The distances round the earth and through it are accurately known. Telegraphic and other means of communication supply the time of the precise moment when the shock took place. When all these facts are taken into account it is found that the vibrations which come through the earth at any great depth below the surface arrive before their proper time. They have, in fact, travelled more rapidly than they would have done if the whole earth had been made of the same material as that which makes up the surface. The study of the facts thus obtained indicates that the outer portions of the earth consist of material three times as dense as water and only slightly denser than the rocks which make up the main mass of the continents. Deeper down the earth's interior is still solid but consists of material having a density six times that of water. Near the centre the condition does not appear to be that of an ordinary solid, but precisely what state it is in is still a matter for conjecture.

The shape of the earth, the up and down movements of its surface, the response or lack of response to the attractive forces of the sun and moon, and a number of other phenomena are all being gradually compelled to add their quota to our knowledge of the earth's interior.

CHAPTER VII

THE CHILDHOOD OF THE EARTH

WITH human history the most complete records available for the historian are those which are most recent. Passing backwards in time, the records for various reasons become fewer and less complete, until, for the earliest ages a few fragments are all that remains for the perusal of the investigator. So it is with the earth itself. A few broad facts, such as those which were discussed in the last chapter are the material from which the story of the earliest stages in the growth of the world has to be constructed.

Our earth is only one member of a group of planets which revolve round the sun, and which, taken together with this, make up the solar system. Whilst some of the members of this system are, like the world, heavy and solid, others, including the sun itself, are light and gaseous. The birth of the world was of necessity intimately linked up with the growth of this system.

The solar system is but one of a vast multitude which make up the universe, each having at its centre a sun. These systems are so widely separated from one another, and from us, that their planets are invisible to us, and their central suns appear as mere points of light, the stars.

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A man walking along the streets sees a baby here, a child yonder, and is reminded of the corresponding stages in his own growth. So likewise among the starry hosts which decorate the skies at night, other systems may be seen less advanced in their development than ours. From them we may hope to gain some idea of the earlier stages in the growth of our own. Peculiarly instructive are the *nebulæ*, irregular vaporious masses looking like drifting fragments of a disappearing mist, but incomparably vaster, covering areas which greatly exceed the limits of our solar system. These are discernible in the all-enshrouding darkness by reason of a faint luminosity. They consist of a material substance, as yet not built up into those complex forms which in our world provide such a rich variety of metals and minerals.

These *nebulæ* (Fig. 7 a) are ragged and tenuous at their margins, but are more concentrated towards the middle, a fact which shows that a feebly-acting gravitational force is already at work within the mass, and that the minute particles of which it consists are gradually falling towards the centre. It is now generally agreed that it was in such a nebula that our solar system had its beginning.

Many *nebulæ*, however, have a more regular form (Fig. 7 b), and are regarded as exhibiting a more advanced stage in development. The centre of each of these is occupied by a large, round, brightly-luminous mass of concentrated material, having a higher temperature and greater complexity of composition than any portion of the irregularly-shaped *nebulæ*. Extend-

ing outwards from this centre there are frequently two streamers, less concentrated and luminous than the central sphere. These are wound more or less closely around the centre, and thus impart to the whole a superficial resemblance to a St. Catherine's wheel in action. The substance which makes up the streamers is irregularly distributed, being concentrated into knots



FIG. 7.—Diagrams illustrating early (a) and later (b) stages in the evolution of nebulae.

at some places, and highly attenuated or even absent in others.

The nebula as a whole is rotating around its centre. These knots, and indeed all the particles great and small that are situated in the streamers, are therefore revolving in circular paths like planets round a central sun. The larger knots may be regarded as exhibiting the earliest appearance of planets as separate entities.

These by reason of their greater mass drew to themselves much of the material that still remained scattered along the streamers.

Opinions differ widely as to the precise changes which these knots experienced during their passage from the nebulous state of the streamer, to the condition described for the interior of the earth in the last chapter. On the one hand, it has been suggested that the streamer consisted of solid particles of various sizes, and that the knots were clusters of these, which became more and more closely packed together until they formed a solid mass. Whilst this was going on, others attracted by this large mass fell into it continually. This process is presumably still going on, at a greatly reduced rate, whenever there is a shower of shooting stars or meteorites. If this be the correct view of the sequence of events, then our world did literally grow in size. At one stage it must, presumably, have been no larger than the moon and, like this to-day, probably had no air around it. As it grew, its attractive force increased until it held the gases that were exuded from the compacting rocks. Thus an atmosphere came into being, and with it clouds and rain, frost and streams, lakes and seas, sediments and sedimentary rocks. Such conditions were favourable to the existence of living things, and so the waters became peopled.

In the opinion of others this is far from being the correct sequence of events. According to them each knot in the streamer became a miniature of the central mass. The nebulous material of which it consisted became more and more concentrated, and its tempera-

ture increased. Thus each knot became a sphere of highly-heated gas. The sphere which formed our world, being so much smaller than some of the others, cooled more rapidly, its gases condensed to a liquid state during which the heavier materials sank inwards, whilst the lighter floated on the outside and eventually solidified to form the stony crust.

Both views, with all their minor modifications, explain many facts, but neither can as yet be accepted as final. Such divergences of opinion always characterise the early stages in the growth of sound theories. When facts are few guidance is required in the search for further facts, and that can best be obtained by attempting to unify those already found. At this stage suppositions or hypotheses abound. The wildest of these is justified if it leads to the discovery of some new fact, or new line of enquiry, or new method of research. Eventually some one explanation emerges which satisfies all critics, and this becomes the established theory.

CHAPTER VIII

OCEANS AND CONTINENTS

WHATEVER the precise changes may have been which took place during the long ages of transition from the nebulous condition, a stage was ultimately reached when the world had approximately attained its present size, and had assumed its present apparently solid condition. At the centre, as revealed by the study of earthquake records, was a core of unknown constitution, and surrounding this was a very thick zone of material akin to nickel iron in composition and density. Enveloping this again was a covering, several hundred miles thick, of rocky material akin to basalt, which has a density about three and a half times that of water. Outside it all was a thin coating of lighter rocky material like granite and allied rocks with a density only two and a half times that of water. Whether this coating was originally continuous over the whole surface of the globe is still a matter for conjecture. In all probability it varied considerably in thickness, and consequently its surface was marked by irregularities of form, rising to appreciable heights here, sinking to extensive hollows yonder. It is possible that this coating was never continuous, and that from the first it was gathered together in great clots of irregular shape and varying

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thickness. These became the primeval continental masses.

If such were indeed the mode of origin of the continents, then the basalt covering would be left exposed between them and would form the floor of those hollows which became the ocean basins.

The rocky material of which the continents consists (Fig. 8), is slightly lighter than that of the basaltic zone which underlies it. Like an iceberg floating in the sea, the greater portion of the lighter continental mass

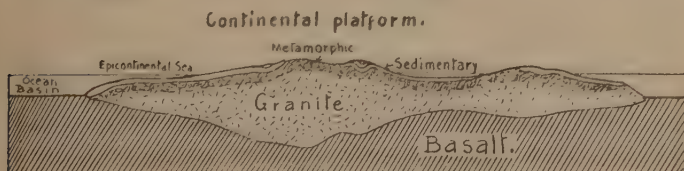


FIG. 8.—Diagram showing the general structure of the earth's crust in and around a continental area.

became submerged in the basalt, whilst only a quite small proportion projected above the general level of the earth's surface. The margins of these projections rose steeply from the comparatively level surface of the ocean floor to a height of twelve thousand or more feet, above which lay the plateau-like continental platform with its gentle slopes and broad plains, diversified by hills and mountains.

By the time that these major features of the earth's surface—the continental platforms and ocean basins—had become blocked out, the temperature of the

earth's crust had become sufficiently low for water vapours to condense. Water was formed in sufficient quantities not only to fill the ocean basins to the brim, but also to overflow on to the margins and flood the low-lying shallow hollows of the continental platform, thus giving origin to the epicontinental seas (Fig. 8). The higher portions alone stood above the waters as dry land.

Enveloping all was the atmosphere, a zone of unknown depth or height, in which clouds floated and from which rain distilled and fell. Rivers and streams flowed. Aided by frost and glaciers they carved the land into diversified forms and transported the débris to the epicontinental seas. Only the finest products, the impalpable dust, went beyond the margin and settled on the continental slopes. The coming into action of these familiar processes marked the opening of a new era in the growth of the world. Hitherto the changes which took place concerned the earth as a whole. The records of these are concealed in the depths of the sky above or of the earth beneath. But now the chief events took place at the surface and are recorded in the sedimentary rocks which are spread like a thin veneer upon the globe, and are therefore much more accessible. From this time onwards conjectures play a less and facts a more prominent part in our reconstruction of the earth's story.

Then as now the sedimentary deposits were piled up in masses twenty or more thousand feet thick. As they accumulated upon the floor of the shallow seas the primeval continental foundations sunk beneath the load

to profound depths (cp. Fig. 2). At first it seems unlikely that the thick, rigid, rocky crust of the earth should yield in this way. It must be remembered, however, that substances that are rigid under normal circumstances become plastic under pressure. Gold and silver take the impression of the die which converts them to current coin. Steel, when it is hot, can be rolled out into rails or even converted to thin wire. At a depth of a few miles the rocks are under such tremendous pressures that they, too, become plastic. When, therefore, as the result of the accumulation of sediments the pressure is increased in any one region, the rocks deep down in the earth's crust yield and move slowly away, into the adjoining portions of the crust where the pressure is relatively smaller. The regions of the surface which overlie these latter portions in their turn rise automatically as this rocky material becomes forced in underneath them.

Sooner or later a region that has been sinking may experience a reversal of its movements. It becomes gradually heaved up ; the sea flows away from it, and the sediments become dry land. Usually this rising does not take place uniformly and consequently one part becomes exposed to the activities of Nature's sculpturing agencies before another. The tilted up portions of the rocks are slowly worn away (cp. Fig. 2 d) and bevelled off layer by layer, until the edge of every layer is seen and even those which had been pushed down to profoundest depths are exposed to view. So the primeval continents which must have consisted at first solely of igneous rock have had plastered on

to them masses of sedimentary and metamorphic rocks.

So far as present knowledge goes, there is no part of the continents that has not passed through the experience just described several times. The result is that there appears to be no region where the first-formed rocky surface of the continents is uncovered. In the heart of every continent there are extensive areas occupied by the most ancient rocks known, but so far as these have been explored they consist only of metamorphic rock which is largely of sedimentary origin.

CHAPTER IX

THE CALENDAR OF THE AGES

THE later stages in the earth's history from the time of the appearance of oceans and continents, lands and seas, are known in much greater detail than those which went before. Every block of stone removed from a quarry, or load of clay excavated in a brickyard, every trench made for the laying down of water mains and electric cables, or mine sunk for coal, opens up a small portion of the later records. Anyone, by carefully observing and noting the facts, may make valuable additions to the sum total of our knowledge of the past history of the earth, for this has not been built up in regular sequence from beginning to end, but by the piecing together of scattered observations, like the fragments of a jig-saw puzzle.

But though our knowledge is a patchwork with gaps here and there, time itself is continuous and flows on from moment to moment without a break. Nevertheless for the purposes of clear description and profitable discussion it is necessary to think of time in terms of artificial divisions. Thus we think of our own life-time in terms of months and years, and of our days as made up of morning, afternoon and evening. Only so are we able to correlate the events of life with one another and

with the experiences of other people. Years and months, days and hours, provide the plain net upon which we embroider the complex pattern of our life's story.

But the events which we now seek to weave into a story happened before clocks and calendars were invented, before the human race had come into being. The periods of time involved are so vast that it is as foolish to express them in years as to tell the dimensions of continents in square inches. Some substitute is, therefore, needed, and a valuable one is provided by the rocks themselves.

Chalk is a well-known rock ; it forms the foundations of the downs, and stands up in towering cliffs along our coasts. In some places it is one thousand feet thick. Examined in thin slices under the microscope it is found to consist largely of minute shells almost identical with those made by tiny creatures that live in countless myriads in the sea to-day. Such little creatures lived also in the seas of bygone ages. They died and their flesh perished, but their shells, usually no bigger than the eye of a needle, fell through the water and came to rest upon the sea floor. As generation followed generation their shells accumulated to a depth of a line, then an inch, then a foot, then hundreds of feet. Ponder upon the smallness of the shell, try to realise the slowness with which a layer merely one inch thick would accumulate. Do not try to think in terms of years, but in terms of that slow drizzle of shells ; then look at a chalk cliff, and realise how very long must be the period of time which elapsed whilst that mass of rock was being formed. That period was a definite portion of the time

that has passed by during the history of the world. It may be called the Chalk or Cretaceous period. Events which happened in any parts of the world may be thought of as taking place whilst the chalk was being laid down in seas that covered much of the British Isles and Europe.

The ranges of hills formed by the chalk in England face westwards over a low-lying fertile plain, the soil of which is heavy because the rock beneath is clay. This clay is used for making bricks and is excavated for this purpose extensively at Peterborough and Oxford. It is called the Oxford clay. It is about six hundred feet thick and contains many shells of creatures that lived in the sea, whilst it was being formed. Like the chalk, it also was formed inch by inch by the settling down of dust in the form of mud upon the sea floor. It also represents a long period of time which may be referred to as the Oxford Clay Period, and many events happened in different parts of the world whilst it was being formed here in the British area.

Each of these two masses of rock, like the months marked upon the calendar, calls up a mental picture of a definite stretch of time, into which certain happenings in the earth's history may be placed like documents in a file. So likewise every layer of rock that underlies the surface of the continents represents a definite period of time.

It is, however, not sufficient to know that there has been a chalk period or an Oxford clay period or any other period. It is necessary to know how these periods are related to one another, which comes first, which

second, which last. The order in which these periods follow one another can be discovered only by finding out the order in which the rocks themselves occur in the earth's crust. This is a long and tedious process. As we have seen, the rocks are almost completely hidden from view by a mantle of soil and vegetation. Moreover Nature, when in playful mood, has twisted the rocks about, and has even turned them upside down. Little by little, however, the work has been done, stretches of sea cliff, boreholes, quarries, railway cuttings, careful mapping of surface features, have each in their turn revealed some small portion of the succession or yielded links which have connected one portion with another.

The combined work of many observers during the last one hundred years has furnished a very reliable account, in broad outlines, of the order of succession of the rocks which occur in the British Isles and other parts of the world. The general result arrived at may be understood by imagining a trench, two thousand feet deep, excavated across Wales and England from Anglesey to the Essex Coast. In the sides of such a trench would be seen the cut edges of many layers of rock (cp. Fig. 9), overlapping one another like slices of thin bread and butter at afternoon tea. The bottom slice was obviously put upon the plate by the maid first. The slice which overlaps it was put down next and the top slice was laid down last. So likewise the layers of rock which come up to the surface in Anglesey slope eastwards and pass beneath those that crop out in the West of England. These in turn dip eastwards under-

THE CALENDAR OF THE AGES

neath the rocks of Essex which are consequently the uppermost and therefore the last to be laid down. Those of Anglesey being the lower must represent the earliest periods of time, those of Essex, on the other hand, the latest.

The whole succession of overlapping strata represents a vast stretch of time, the impressive length of which can be only vaguely conveyed to our minds by such estimates of duration as sixty million to three hundred million years.

Some of the layers of rock, e.g., Oxford clay, contain

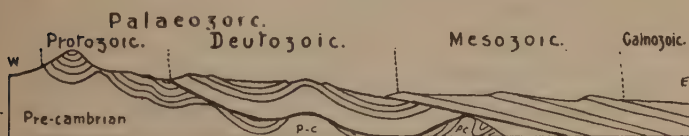


FIG. 9.—Diagrammatic section across England and Wales, showing the general arrangement of the sedimentary rocks in relation to one another, and the groups into which they are classified from the standpoint of the time when they were formed.

the shells and remains of marine animals, thus proving that these strata were formed as deposits in the sea. Others, e.g., red sandstones and marls of Warwickshire, bear the marks of rain-drops, cracks caused by the drying action of sunshine, footprints, and may even contain the bones of land animals—all indicating the fact that these rocks in their turn were formed in hollows on the surface of the land. Thus the succession of rocky layers supplies us with a cinematographic view of the history of that portion of the earth's surface now

occupied by the British Isles. As it unrolls, the scene is for ever changing: at one time a sub-tropical sea dotted with volcanic islands, then a forested lowland along the margin of a lost continent. Gradually the forests disappear, mountains rise and a desert landscape fills the view, and in the fullness of time our islands as we know them begin to take shape.

Along with these physical changes there go also changes in the forms of life. The animals whose remains are preserved in the oldest rocks are strange and unfamiliar and often quite unlike those of to-day. In the later rocks this strangeness declines and a vague familiarity pervades the appearance of both aquatic and terrestrial types. In the latest rocks the animals, apart from quaint touches of strangeness, resemble those of to-day to a marked degree. These changes may, therefore, be thought of as a series progressing from ancient and old-fashioned to modern and up-to-date. It is customary to divide the time, which has elapsed since the period represented by the earliest fossil found in the British Isles, into three great divisions, *Palæozoic*, *Mesozoic*, *Cainozoic* (*zōē*=life, *palaaios*=ancient, *mesos*=middle, *kainos*=recent). Various names have been suggested for the periods preceding the *Palæozoic*, but the term *Pre-palæozoic* will serve the purpose of this book. Rocks formed during the *Pre-palæozoic* ages are found in various parts of the world, including the British Isles, but as yet very little is known about the forms of life which lived then. The *Palæozoic* period lasted very much longer than either the *Mesozoic* or *Cainozoic*. It has, therefore, become the custom to

THE CALENDAR OF THE AGES

divide it into two parts, the Early Palæozoic or *Protozoic* (protos=first) and Late Palæozoic or *Deuterozoic* (deuteros=second).

These larger divisions of geological time are further divided and subdivided in accordance with increasing and more detailed knowledge of the rocks and fossils. For the naming of these subdivisions there is no system of terminology. Sometimes the period of time is named after the region where rocks laid down during the period were first explored, e.g., Cambrian after Cambria in Wales, or a name may be given which reflects the nature of the dominant rock, e.g., Cretaceous from creta (=chalk), or some peculiarity of arrangement, e.g., Trias, which refers to the threefold character of the constituent parts of the rock. The main subdivisions are given in the accompanying table which should be read from below upwards, from the earliest to the latest :

CAINOZOIC OR TERTIARY (from kainos=new, recent) :

Recent		
Pleistocene	$\left. \begin{array}{l} \text{pleisto}=\text{most} \\ \text{pleiōn}=\text{more} \\ \text{meiōn}=\text{less} \\ \text{oligos}=\text{few} \\ \text{eos}=\text{dawn} \end{array} \right\}$	cene from kainos.
Pliocene		
Miocene		
Oligocene		
Eocene		

MESOZOIC OR SECONDARY :

Cretaceous (creta=chalk).

Jurassic (these rocks make up the mass of the Jura Mountains).

Triassic (the rocks have a threefold arrangement in Germany).

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PALÆOZOIC OR PRIMARY :

Deutozoic—

Permian (Perm is a province in Russia).
Carboniferous (coal consists mainly of carbon).
Devonian and Old Red Sandstone (Devonshire).

Protozoic—

Silurian { Silures } were British tribes which lived
Ordovician { Ordovices } in those parts of Wales
Cambrian (Cambria = Wales) occupied by these rocks.

PREPALÆOZOIC OR PRECAMBRIAN :

A sober estimate of time in terms of years assigns six million to the Cainozoic, thirty million to the Mesozoic, and sixty million to the Palæozoic.

CHAPTER X

THE GROWTH AND DESTRUCTION OF MOUNTAIN RANGES

WITH the rocking up and down of the continents, and the alternate submergence and emergence of their low-lying portions, successive layers of rock are plastered on to their surfaces. Over considerable areas such as

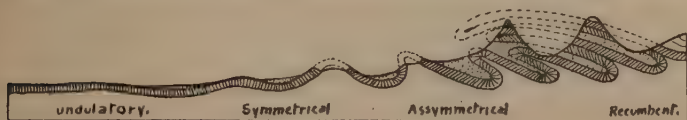


FIG. 10.—Section showing the varying degrees of folding exhibited by sedimentary rocks.

the Great Plains region of North America and the Central Plains of Europe, these layers lie flat or nearly so. Alongside of them, however, stretch belts where the rocks are intensely crumpled and cleaved. Between these two extreme conditions (Fig. 10) there are many gradations in degrees of folding from broad, low undulations, through high, steep-sided but symmetrical folds, and folds which are asymmetrical because they lean over on one side, to those which, as it were, have fallen flat upon one side and on that account are described as recumbent folds.

These various gradations, and the way in which they have been produced may be illustrated by a simple experiment. Spread a thick towel upon a table and put the hands down flat and firmly upon it, one at each end. Move the hands slowly towards one another so that the portion of towel under each slides over the table. The middle portion of the towel will now begin to ruckle. At first the folds will be symmetrical, but eventually they will rise and fall backwards over the hands. In like manner the layers of rock which once covered the region which is now a mountain belt have been squeezed sideways, apparently as the result of the closer approach to one another of such broad, level, more rigid portions of the earth's crust, as the floors of oceans or extensive plains on the continental platforms.

This closer approach may be the outcome of the continued cooling of the earth as a whole. The passage outwards of the internal heat of the earth takes place so slowly that its effect upon the temperature of the surface does not amount to more than one fifth of a degree Fahrenheit. Nevertheless, given long periods of time, this may produce a perceptible cooling and consequent shrinkage of the earth. This necessarily involves a decrease in the area of the surface of the globe. The solid crust must, therefore, adjust itself to fit into this diminished space. In so doing its portions squeeze against one another with the result that those which are weaker or less rigid yield in the way described above.

Whilst this may be the main influence at work no doubt other factors play a part. Thus, for example, it has been already noticed that over long stretches of sea

floor deposits accumulate to great thicknesses and depress the underlying portions of the earth's crust. Each layer of deposit when laid down has the normal temperature of the earth's surface, but when, as the result of the piling of other layers upon it, it is pushed down to great depths its temperature rises, partly because the interior heat of the earth is conducted into it, partly because of the heat produced by the disintegration of radio-active material within it. This increase of temperature leads to an expansion both upwards and sideways of the more deeply seated layers of rock with a consequent upheaval of the surface layers. The lateral pressures produced may also play a part in the processes of crumpling, and spreading outwards of the folds on to the margins of the more rigid areas of the earth's crust on either side.

These explanations and others that need not be discussed are by no means universally accepted. They are as yet merely working hypotheses which seem to give some clues to the mechanism of mountain building.

Closely associated with mountain building are the phenomena of earthquakes and volcanoes. Maps of the world showing the regions where these occur most frequently show that their distribution coincides to a marked degree with that of the great mountain axes. This is especially the case for those which fringe the margins of the Pacific Ocean and make up the islands of both the East and the West Indies. In studying such maps it should be borne in mind that the strings of islands that form such a prominent feature on the

western side of the Pacific are to be regarded as the crests of submerged ranges.

Many earthquakes are, no doubt, due to the vibrations set going when layers of rock slip over one another or snap suddenly along a line of breaking or faulting.

It has also been suggested that, when layers of rock are bent upwards into folds, these act like the archway of a bridge and support much of the weight of the rocks. Underneath the fold the vertical pressure, which existed when the rocks were flat, has been reduced. That pressure played a part in preventing the highly-heated rock beneath from melting. On its removal the rock became liquid and gave rise to all the phenomena of igneous intrusion and volcanic extrusion described in a previous chapter. This again must be regarded only as a working hypothesis which, at any rate, unites a number of otherwise disconnected facts.

All these processes take place with exceeding slowness. Indeed, it is not unlikely that the earthquakes which occur with such frequency around the Pacific are but indications that the mountain building is still proceeding.

Whilst the mountain systems are thus gradually rising and rearing their mighty crests to the skies, the rain and frost, sunshine and rivers are not inactive. On the contrary, no sooner does the bulging earth rise above the surface of the sea than all these agencies come immediately into action according to time and season, and rend the particles of the rocks asunder, and carry the waste away to the sea or lowland basin to form the rocks of future ages. The surface level of the mountain

THE GROWTH AND DESTRUCTION OF MOUNTAIN RANGES

region at any given time is resultant of these two great processes, uplift and denudation. For long periods of time the folding and upheaving processes are dominant, the ground then rises more rapidly than it is worn away, and lofty systems like the Alps and the Andes are the result.

In due course the crustal forces weaken, and the rate of rising slows down. The processes of erosion and transport, however, continue; the valleys become excavated and their floors are reduced almost to sea-level. For them the processes then practically cease, but the hills and mountain-peaks that lie between still stand exposed four-square to the destructive agencies. They, too, are gradually disintegrated, and the débris transported thence, so that in due time they, too, are brought down almost to the level of the valley floor. What was once a great mountain system has thus been reduced to a plain which, to distinguish it from other plains, is called a *peneplain*.

CHAPTER XI

THE PHYSIOGRAPHIC CYCLE

IN course of time then the loftiest mountain regions are reduced to peneplains. These are consequently very complex in structure, the rocks are broken by faults, and intensely folded, the finer grained among them are cleaved and are converted into more or less perfect slates. For extensive areas the rocks of both sedimentary and igneous origin are metamorphosed into schists and gneisses. Here and there great masses of igneous rock are exposed to view and valuable metals and ores lie near to the surface and are accessible. The eastern half of Canada, and the country bordering the northern end of the Baltic, are examples of such a region.

In striking contrast to such a plain is one in which the rocks are flat or only gently undulating. Here monotony of constitution as well as of the surface is characteristic.

The region occupied by either kind of plain may sink or rise. If it sinks the sea flows over it, and its surface becomes buried under deposits which in time form flat layers of rock. The old land surface then becomes a plane of unconformity in the rocks, that is to say, a plane where there is a break in the sequence, a gap in the record of the rocks, corresponding to a longer or

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shorter period of time. In this case the unconformity is a very marked one for it represents a very long period of time during which the older rocks were uplifted, folded, denuded and finally submerged.

On the other hand, a plain, whether of the simple or the complex type, may be uplifted several hundreds or even thousands of feet above the level of the sea, and thus may become a plateau. The rivers that meandered sluggishly across its surface when it lay at lower levels then become rejuvenated. Their waters escape rapidly down the steep sides of the plateau in cascades and waterfalls which excavate narrow gorges bounded by precipitous slopes. With the freer movement of the water in the lower reaches, the rate of flow increases in the upper reaches also. Consequently, the channel is deepened and the surface of the plateau is rapidly etched by narrow valleys which wind and meander in close accordance with the course of the aged stream which has been reawakened to the vigorous activity of youth once more.

As time rolls by, the deepening of the river channel continues uninterruptedly, with the result that, in arid, almost rainless regions like Colorado, canoñs and gorges of profound depth are produced. In more humid climes the rain, aided by frost and other agencies, breaks up the rocks on either side, and washes the débris down to be carried away by the river. Thus the potential gorge is widened to become a wide, open valley. Between the rivers broad expanses of the old surface of the peneplain still remain (Fig. 11 a). The plateau region has been cut up or dissected, and has become a

collection of table-topped mountains or hills, separated by deep gorges or valleys according as the climate is dry or moist. Devon and Cornwall and the Ardennes are examples of such dissected plateaux.

Gradually the floor of each valley is lowered almost to sea-level through an ever-increasing portion of its length. At the same time the processes which widen the valleys concurrently reduce the width of the intervening table lands (Fig. 11, a, b), until the last traces of the old peneplain disappear and the only indication of the original plateau is seen in the fact that all the tops of the hills or mountains rise to a common plane. Such is the case in the Grampian highlands of Scotland, which thus provide an example of a maturely dissected plateau.

As denudation continues the mountains and hills are worn away from summit to base until the whole region once more becomes a peneplain. Thus one complete cycle of uplift and denudation with its regular sequence of changes in valley and upland has been completed. This is called the *Physiographic Cycle*.

It is, however, the rare exception for such a cycle to run its course uninterruptedly. Uplift may be renewed once, twice or a number of times even before the stage of mature dissection has been fully attained. On the other hand the region may be lowered as a whole, and more or less completely submerged. Provided, however, that a region remains above sea-level long enough there comes a time when the successive uplifts cease. Denudation then pursues its course relentlessly to the end, which is the peneplain.

Even though a region may be low-lying and almost flat like Anglesea, the Outer Hebrides, Finland, or the Hudson Bay Lowlands, the metamorphosed condition of the rocks, the folded and cleaved state of the strata, reveal the fact that here earth pressures, stresses and strains once found relief in mountain building, and that here lofty cordillera once existed.

Along the coastal margin of the North-Western Highlands of Scotland a portion of the same peneplain which makes up the Outer Hebrides is found. Here on



FIG. 11.—Three stages in the cycle of denudation. a, early stage, plateau dissected by narrow, steep-sided valleys, b, mature stage, with valleys and plateau fragments about equally extensive, c, advanced stage, when plateau has been reduced almost to a plain-peneplain.

the mainland, however, it disappears eastwards beneath the flat-bedded sandstones of Precambrian age, carrying our thoughts with it into that far distant era. Already within the limits of that age the whole sequence of events described took place and was completed—the piling up of a great accumulation of sediments, the metamorphosing of these at profound depths, the injection of masses of igneous rocks, the crumpling up of the whole complex into mountain systems, the destruction of these, the repeated uplift, dissection and

peneplanation of their foundations, and the final burial under many thousands of feet of fine silts and coarse sands. The contemplation of it all creates an overwhelming sense of the vastness of the time involved in that one episode of the earth's history.

During Palæozoic and later times denudation has removed a portion of the covering of silts and sandstones, and has exposed that birthday landscape to view once more. In the heart of every continent extensive areas of similar Precambrian land surfaces are thus preserved. It is not unlikely that large portions of these have never been submerged or covered since that far-off epoch, and have therefore passed through the vicissitudes of the physiographic cycle an indefinite number of times.

Earth stresses and strains have found relief in the folding and fracturing of the rocks more or less continuously down through the ages. There have, however, been greatly varying degrees in the vigour and extent of this release. During long periods it has been so gentle that denudation and deposition predominated everywhere, continents were peneplaned, and epicontinental seas were filled. The land was then, on the whole, low-lying with broad coastal margins lying near sea-level and fringed by extensive swamps. A slight movement downwards led to great transgressions of the sea ; upwards, to equally great recessions.

At other, relatively short, periods the strains and stresses reached a climax and found expression in great mountain building movements and associated volcanic activity, which for a time predominated over the pro-

cesses of destruction and deposition. These periods occurred at wide intervals, viz., during the Precambrian, about the middle of the Palæozoic, the close of the Palæozoic, and at the close of the Mesozoic and during the Cainozoic. These movements may be referred to respectively as the Huronian, Caledonian, Hercynian and Alpine.

The mountain systems formed before the close of the Palæozoic have all experienced complete peneplanation and have become involved in the physiographic cycle. Peneplains and dissected plateaux derived from them form the uplands of South Scotland, of South Wales, of Cornwall and Devon, and the Ardenne region.

The mountains formed during the last period are now undergoing denudation for the first time. They therefore form more striking features on the earth's surface than do the remnants of the Palæozoic mountain systems, and consequently loom more largely before our eyes. Among these are included the great ranges which lie along the western flanks of the American continent and traverse the heart of the Old World from Spain to China.

CHAPTER XII

CONTINENTS VANISHED AND STRAYED

FROM all that has gone before, it is evident that shore lines are ever shifting, and that the distribution of land and water has never been the same for two successive periods down through the ages. In consequence of this, each continent to-day is a complex built up of fragments, more or less extensive, of the land masses of the past.

Built up as they have been by the same agencies, and out of the same material, there is a general similarity between the continents. Thus all but the youngest rocks are buried to a large extent beneath the later ones. Here and there, however, the strata have been tilted and folded, and the more elevated portions have been removed, with the result that older rocks of all ages are now exposed and accessible to examination. Where this has taken place the outcrops of the strata, that is to say those areas where the strata come up to the surface, occupy more or less parallel strips of country. The superficial features of these are determined by the varying resistance of the rocks ; ranges of hills by the harder or more resistant sandstones and limestones ; the plains by the softer and less resistant clays. This regular arrangement of rocks and features gives to the

land a grained character like that of a piece of wood.

Along the western flanks of America the trend lines of the graining, associated with the dominant mountain ranges, run parallel to the coast. This relationship of grain to oceanic margin is maintained all around the Pacific.

In the old world, the trend line of structure of the dominant mountain systems lies east to west, and cuts across the heart of this great cluster of land masses. At their western end in North Africa and Spain, they strike the Atlantic coastline almost at right angles. This type of relationship between the oceanic margin and the grain of the adjoining land appears to characterise the Atlantic, and distinguishes it from the Pacific.

The Caledonian (Mid Palæozoic) and Hercynian (Late Palæozoic) movements gave rise to mountain systems of Himalayan proportions both in North America and Europe. These have since suffered peneplanation, uplift and dissection. In America the roots of these great systems, known as the Appalachian Mountains, occupy an immense tract of country stretching from Alabama to New England. The grain trends from south-west to north-east across the United States and strikes the coastline obliquely between New York and Quebec. This coastline is very irregular, having deep indentations and projecting peninsulas with their long axis in continuation with the grain. Nova Scotia, which is almost an island, and the islands adjoining this coast, including Newfoundland, are built of the same rocks and have the same directional trend and history.

They are, in fact, fragments of this Appalachian belt. As the eye travels along this belt from the interior of the continent to the coast and across the straits to the islands, the questions naturally arise: How much further out into the Atlantic region did it extend originally? Are other portions submerged beneath its waters?

On the European side the denuded foundations of these ancient systems are not always so continuously exposed as in America. Those belonging to the Caledonian system occupy the major portion of Scandinavia, and have the same directional trend as that peninsula. At its south-western end they break off abruptly against the coast to reappear in the highlands and uplands of Scotland, and of the North of Ireland. Here once more they are truncated by the coast. The foundations of the Hercynian system have been much more broken up, and large portions are buried under later rocks. Nevertheless considerable fragments remain at the surface, and form the upland regions of Bohemia, Ardennes and Eifel, the Central Plateau of France, Brittany, Cornwall and Devon. Thus the remnants of both these ancient mountain systems carry the thoughts out to the Atlantic Ocean, and suggest the same questions as before.

Other features of the opposing coastlines of the Atlantic are equally intriguing. The complex of metamorphic and igneous rocks of the outer Hebrides and the North-West coastal margin of Scotland have their counterpart not only in Scandinavia, but also on the other side of the ocean in Canada. Are these fragments

of a larger whole? Are other fragments submerged beneath the ocean? A similar kinship of composition and structure seems to exist between the borders of Africa and those of the east coast of South America, and between Madagascar, India and Australia.

Many other facts of a more detailed nature relating to the constitution of the rocks themselves, and to the



FIG. 12.—Map showing distribution of land (plain) and sea (dotted) during the carboniferous period, according to the landbridge hypothesis.

fossils they contain, give rise to a feeling amounting almost to conviction that these various land masses were once united with one another across the present oceans. Two possible modes of connection can be conceived. Either the present oceanic areas were occupied by land masses which have foundered, and now lie submerged beneath their waters; or the existing continents were directly connected with one

another forming larger entities which broke into pieces that have since drifted asunder.

The former view is the one which has for long held the field (Fig. 12). This postulated a North Atlantic continent bridging across from Europe to North America, and a great Southern Continent—Gondwanaland, bridging the Indian and South Atlantic

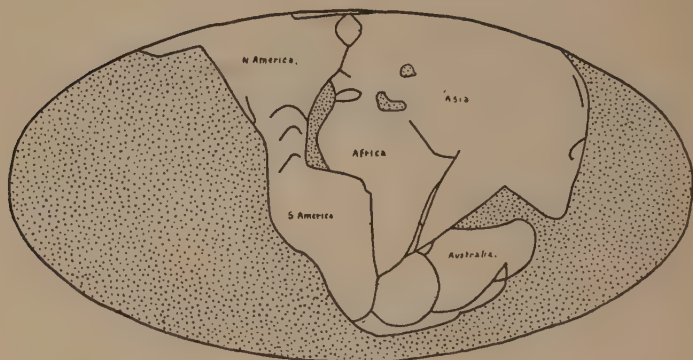


FIG. 13.—Map showing distribution of land (plain) and sea (dotted) in carboniferous times according to the continental drift hypothesis.

oceans, and incorporating Australia, the peninsula of India, Antarctica, Africa and South America. This may be called the "Landbridge Hypothesis."

The other view is one which has been brought prominently forward in quite recent years (Fig. 13). According to its chief exponent all existing continents formed portions of one large continent in late Palæozoic times. This became broken up by the appearance of

long lines of fracture similar to those which now form the Jordan Valley and Dead Sea trough, and extend as rift valleys nearly the whole length of Africa along the line of the great lakes of Victoria, Tanganyika and others. The fragments of this great continent gradually separated, and these rents widened, forming at first long narrow seas, but eventually they became the oceans. This is the "Continental Drift Hypothesis."

The conceptions of continents foundering and continents drifting are both equally startling, and make equal drafts upon the bank of imagination. Each has its staunch supporters. Both hypotheses explain many facts and are therefore worthy of serious consideration.

CHAPTER XIII

WATER AND AIR

WATER covers three-quarters of the globe, it fills every ocean basin and overflows the brim. It penetrates every nook and cranny and percolates through every pore in the rocks which make up the earth's crust. The air, on the other hand, completely envelops the earth, and rises to heights above its surface probably exceeding two hundred miles. Whence have all this water and air come? An answer to this question is suggested by recalling the fact that at every volcanic eruption great volumes of steam and many kinds of gases are set free. These must have come from the magma, in which the constituents of which they consist were dissolved. As the magma cooled the other substances it contained cooled and consolidated, but these constituents alone remained in liquid or gaseous state. In view of these facts then, it is fair to suppose that the ingredients both of water and air were present in the original nebula. Those substances which consolidate at higher temperatures, have formed the solid, heavy earth. In the course of coming ages the temperature may sink so low that all the water will freeze, and the air itself liquify and become solid. Fortunately that time has not yet arrived. Water and air then are

to be regarded as the last products in the consolidation of the earth, products which still remain liquid and gaseous at existing temperatures.

The water when it first condensed was pure, but as it fell in drops it dissolved the more soluble constituents of the primeval atmosphere, some of which, such as chlorine, hydrochloric acid, nitric acid, are, as already seen, set free at volcanic eruptions. Armed with these chemically very active substances in solution the water percolated into the rocks. It eventually issued forth in springs, but left these acids behind chemically united with the rocks. Thus the atmosphere became purified, and oxygen, nitrogen and carbonic acid gas remained as its chief constituents.

The rain, when it falls, still takes up small quantities of these gases also into solution, and, as it flows along underground, leaves some oxygen and carbonic acid behind chemically united with the rocks and minerals through which it percolates.

Chemically pure water is one of the rarest things in Nature ; the rain as it descends soon dissolves the gases of the air, and as it percolates through the ground it takes up various substances into solution. Natural waters vary greatly in the quantity of material they hold in solution. The following figures showing the percentage of solids in solution will illustrate this :

Rain water	...	...	...	...	0.004%
River and lake waters	...	...	...	...	0.005% - 0.07%
Sea water	...	...	...	...	3.5%
Water from the Dead Sea	...	...	...	...	24.0%
Water from Lake Van	...	...	...	...	33.0%

Between fresh water and sea water there is a great difference, not only in the fact that the latter holds fifty times as much material in solution as the former, but also in the fact that, though the same substances are present, the proportions of these differ greatly. Thus, for example, salt forms only one-fiftieth of the solids in solution in fresh water, but more than three-quarters of the whole in sea water. Practically all the salt that has been brought down to the sea by the rivers through the ages is still there, for there are no processes at work which tend to remove the salt permanently from the sea. On the other hand, the water that is poured by the rivers into the oceans, evaporates and is carried in the clouds back to the land once more. The result is that the sea becomes progressively more salty with the passage of time.

Equally striking is the difference in the relative quantities of carbonates, especially of carbonate of lime. This makes up no less than three-fifths of the solids in fresh water, but only one-thirtieth of that in sea water. There are two chief reasons for this. On the one hand, carbonate of lime is not as soluble in salt as in fresh water, and consequently much is precipitated as a fine mud at the mouths of those rivers that are rich in lime. On the other hand, innumerable sea animals extract the lime from the water, and use it for making their shells.

Whilst the rocky earth and liquid seas are beneath our feet the air is all around and above us. It is so much lighter and more attenuated than water that we are hardly aware of its existence ; furthermore, it is very

compressible. The topmost layers are therefore the most attenuated, and the bottommost layers, being subjected to the combined pressure of all the air above them, are so dense that no less than one-half of the total substance of the atmosphere is compressed into the lowest three and a half miles.

The lower strata of the air consist mainly of oxygen and nitrogen in the proportion of twenty-one parts to seventy-seven per hundred. Water vapour and carbonic acid gas are the next most important constituents, but they occur only in such small quantities as twelve and three parts per thousand. With the passage upwards into the higher strata of the atmosphere the composition gradually changes. The constituents which are dominant in the lowest strata gradually diminish and eventually disappear ; the water vapour at a height of nine miles, carbonic acid gas at eighteen, oxygen at seventy, and nitrogen at ninety miles. Above this height helium appears to be the sole constituent.

During the last few years rapid progress has been made with the investigation of the upper air. One of the most striking discoveries has been the fact that the regular decrease in temperature of one degree Fahrenheit for every rise of three hundred feet continues only up to a certain height, which is about seven miles for the British Isles, but that above this level no appreciable change of temperature with increasing height takes place. Observations of a like character in other parts of the world are sufficiently numerous to prove that the atmosphere is divided into two clearly-defined layers, a lower, the *troposphere*, where the change takes place ;

and an upper, the *stratosphere* where the temperature changes with latitude, but not with height. The zone or boundary between the two is called the *tropopause*, which varies a little in level with the seasons, and is higher over the Equator (ten miles) than over the middle latitudes (seven miles).

Inasmuch as the atmosphere has, from the beginning, been a part of the world, even its most attenuated portions inherit the movements of the primeval mass, clinging to it as it moved round the sun, and rotating with it as it spun upon its axis. Just as a nail driven into the rim of a wheel has a longer path and therefore travels more quickly than one stuck into the hub, so the air resting upon the Equator travels with the velocity of one thousand miles per hour, whilst that of the poles is relatively at a standstill.

If the air were a globe of rigid glass, the motions just described would be the only ones. Such is, however, not the case ; it is a gaseous, highly-fluid substance, which responds rapidly to differences of temperature and degree of compression between one region and another. These and other influences as yet not fully understood have been in action since quite early stages in the growth of the world, and consequently large movements within those described above have been maintained down through the ages. Though much is known about these movements, much still remains to be elucidated.

PART II

THE WORLD OF LIVING THINGS

CHAPTER XIV

LIFE IN ITS LOWLIEST FORMS

HITHERTO only the physical aspects of the growth of the world have been considered ; the concentration of nebulous matter to a globe of rocks and minerals enveloped in water and air ; the shattering of the rocks and the re-arrangement of the *débris* to form other rocks. The same processes have been endlessly repeated down through the ages. The same material has been laid down here, torn away and transported yonder, and then once more removed and conveyed elsewhere. The clay which is forming to-day is, in all its characteristics, so like the clays formed at the opening of geological time, that only a specialist can detect the differences, when such exist. The products of physical processes—rain from heaven, sand of the desert, muddy ooze upon the ocean floor—are monotonously alike down through all the ages.

In the midst of these physical surroundings there appeared, in ways as yet unknown and only dimly imagined, something called living substance or *proto-plasm*. This has undergone continual and progressive changes as the ages have rolled by ; and the forms it has assumed are unique for each period, being distinguished with comparative ease from all that have

gone before or have followed after. To-day protoplasm is the most complicated material, chemically and physically, upon the face of the earth, and manifests itself in a greater multitude of different forms than any other known substance. It has spread over the floor and through the waters of the sea. It has covered the land with a carpet that has redeemed the continents from being mere wildernesses of rock.

One of the simplest forms assumed by protoplasm is exhibited by the *Amœba* (Fig. 14 a). This lives among the rotting vegetable material that usually lies upon the floor of pools and ponds. It is too small to be seen by the unaided eye, and must, therefore, be examined by means of a microscope. In appearance it is like a colourless, irregularly shaped blob of jelly. Its outer surface is made up of a layer of clear viscous material which is difficult to see. This is called the *ectoplasm*. Within this, and making up the main bulk of the body, is a more fluid granular material, the *endoplasm*. Near the centre is a compact oval body; this is the nucleus. Experiment has proved that, if an *Amœba* be cut into two pieces, that which contains the nucleus lives, the other dies. In some way the welfare of the whole of that small particle of protoplasm is closely linked up with the presence of the nucleus. A nucleus, together with the small mass of protoplasm with which it is associated, is known technically as a cell. Many living things consist of a multitude of cells; the *Amœba* consists of only one.

By making a series of outline sketches (Fig. 14 a) of the *Amœba* that is under observation, it is soon dis-

covered that the creature is perpetually changing its shape, swelling out in one part, contracting in another, with the result that it also changes its place and moves about from one part of the field of vision to another. If in the course of its travels it comes in contact with a bit of stuff that is suitable for food, the protoplasm, as it were, flows round on all sides and engulfs it. On the other hand, particles of sand and grit are passed by. The Amœba, in addition to being able to move about, is therefore sufficiently responsive to differences between

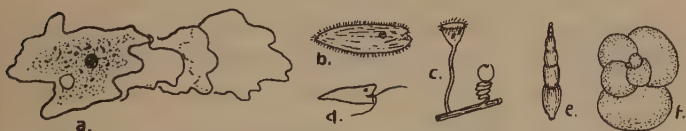


FIG. 14.—Various forms assumed by unicellular animals (protozoa)
 a Amœba, outline on the left shows the structure of its body, series of outlines on the right illustrates the way it moves from place to place. b paramœcium or slipper animalcule, c euglena, d vorticella or bell animalcule extended and retracted, e and f, shells made by amœba-like forms called foraminifera, e straight shell, f coiled shell.

other substances to enable it to distinguish those which are good for food, from those which are not.

Within the endoplasm each particle of food becomes enveloped in a minute sac of fluid which dissolves or digests it. Any indigestible portions are ultimately ejected from the body. In the endoplasm there also appears, at regular intervals, a clear space, filled with clear liquid, which increases to a certain size extending outwards to the edge of the ectoplasm ; it then collapses suddenly with the expulsion of its fluid contents into

the surrounding water. This fluid contains the waste products of the body. As the result of the feeding and digestive processes, the *Amœba* grows, but not as a crystal grows. In the latter, new material is merely added to the outer surface; but in the former it is interposed into and throughout the substance of the body. When the *Amœba* attains a certain limited size, growth ceases. The nucleus now divides into two, the body follows suit, and two *Amœbæ* are the result. Thus the *Amœba* has reproduced its kind. This mode of reproduction by simple division is called *fission*.

The *Amœba*, like other living things, needs oxygen. The process of taking this in and using it is called respiration. If, for any cause, the supply of oxygen fails, the creature dies.

The food and oxygen thus taken in are built up into the complex substance which constitutes protoplasm. This substance is very unstable, and quickly breaks down into those simpler substances, including carbonic acid gas, which become the waste products of the body's activity. Thus the protoplasm is in a state of perpetual renewal and destruction. All these processes are spoken of collectively as *metabolism*, those concerned only with renewal and upbuilding as *anabolism*, those concerned in the breaking down as *katabolism*. Whilst metabolism goes on, the phenomena of life described above are manifested; when that ceases, they cease. The *Amœba* is but one of a great multitude of minute animals whose bodies consist of only one cell. These are all classed together as the unicellular animals, or Protozoa. Most of these, unlike the *Amœba*, have a

definite and unchanging form (Fig. 14 b, c, d), with clearly defined spots on the surface of the body for the intaking of food, and the extrusion of the waste material. Some like the Slipper animalcule or *Paramœcium* swim rapidly about from place to place by means of cilia or delicate bristle-like projections of the protoplasm which vibrate rapidly to and fro. Others, like the bell animalcule or *Vorticella*, are permanently attached to weeds and other objects by means of a stalk. When shaken or by any means disturbed it contracts its stalk rapidly into a corkscrew spiral, and the brim of its bell-shaped body closes inwards. *Euglena* is a spindle-shaped protozoon, but the position of the swollen part of the body shifts from front to back as the creature crawls along. At its front end there is a long whip-lash-like thread of protoplasm, which by its movements can either draw the animal rapidly along or create a minute whirlpool in which particles of food are caught and carried to the spot where food is taken in.

In the sea vast multitudes of protozoa, which resemble the *Amœba* more closely than the other types that have been mentioned, live and produce tiny but exquisite shells of lime (Fig. 14 e, f). These are classed as the *Foraminifera*. Some idea of their significance and abundance may be gathered from the fact that no less than one-third of the ocean's floor is covered by their shells. The deposit thus formed by them is called *Globigerina Ooze*. Some of these *amœba*-like creatures abstract silica from the water, and produce shells of rare beauty resembling spheres of the finest lace woven with crystal threads.

Protozoa play a prominent part in the economy of life upon the land as well as in the water. Some inhabit the soil and play their part in influencing its fertility. Some enter the flesh, blood and organs even of mankind and engender diseases and fatal sickness, especially in tropical lands.

Notwithstanding the simplicity of the single cell the protoplasm of which it consists not only exhibits such properties as mobility and sensitiveness, and performs such functions as digestion, respiration and reproduction, but, as shown by the examples just enumerated, it exhibits a remarkable power of adaption to all the varied conditions met with in water, on land, and in the bodies of higher animals.

CHAPTER XV

GRADES OF ANIMAL STRUCTURE

SOME Protozoa are colonial in habit. When division takes place the new individuals remain united with one another. Repeated division therefore gives rise to a cluster or colony of individuals. Nevertheless each member of the colony lives independently of the rest, so much so, indeed, that if one be detached the rest do not suffer.

In certain lowly creatures called sponges, and classed as *Porifera*, a different type of clustering takes place. This is best exemplified in one of the simplest sponges. The body is shaped like a vase (Fig. 15 a) with its sides pierced by innumerable holes. During life water flows through these into the cavity of the vase and escapes at the mouth. When a thin slice (Fig. 15 b) of the wall of such a sponge is examined under the microscope it is seen to consist of a number of cells each having the same fundamental parts as an *Amœba*.

Some cells are concerned only in collecting and digesting food; some in secreting minute rods or spicules of lime or of silica, or long threads of a soft silky material called spongin, all of which function as a supporting framework or skeleton for the whole body. Some cells are flat, and form a thin covering on the

surface of the body. Other cells, which are remarkably like *Amœba* in appearance, are called reproductive cells, because, when they are ripe and fertile, they are cast forth from the body into the water to give rise to new sponges.

The formation of a new sponge takes place in the following manner. The cell divides into two, but the halves remain united. Each half again divides, and

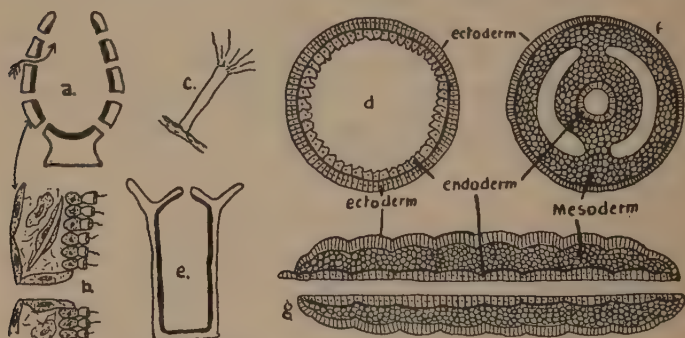


FIG. 15.—Fundamental grades of structure exhibited by multicellular animals (metazoa).

a and b, grade with ill-defined tissues ; a, diagrammatic section of a simple sponge ; b, highly magnified section of part of the same sponge.

c to e, grade with *two* well-defined primary tissues ; c, hydra attached to a stalk ; d, magnified section across the body of a hydra ; e, longitudinal section of hydra.

f and g, grade with *three* well-defined primary tissues ; f, diagrammatic section across the body ; g, diagrammatic section parallel to the length of the body.

redivides repeatedly until a great multitude of cells is formed, all of which remain united together to form one large body, the sponge. Whilst all this is taking place

GRADES OF ANIMAL STRUCTURE

the various cells become modified for doing special work, for collecting and digesting food, for building up a skeleton, for covering the body. Some appear to have no special properties, but are nevertheless potentially able to perform all these functions, for they act as reproductive cells, and therefore transmit these powers to the cells which build up the body of the new sponge.

A sponge is therefore not a mere colony of cells, in which each individual performs all the functions of a creature like an *Amœba*. On the contrary, the various functions are to some extent separated, and are performed by special cells. Here, then, is a differentiation of function accompanied by a differentiation of cells. This has become possible because the cells instead of separating remain united. As already seen, the unicellular animals are called Protozoa. All other animals are multicellular and exhibit this marked differentiation of parts and function. These are classed as *Metazoa*.

Because sponges produce skeletons they are not infrequently found preserved as fossils in the rocks. Sponge spicules are found in Cambrian strata, thus proving that sponges already existed in Cambrian times.

Every sponge, no matter how large and complicated, starts life as a single cell, and is built up from that cell by repeated division. It is impossible to contemplate this fact without being strongly tempted to believe that it was in some such way as this that sponges originated from Protozoa far back in the Precambrian Ages. That the rocks should contain records of these stages of

progress is not to be expected. It is very improbable that records could be stowed away in the rocky archives of Nature before the art of secreting stony skeletons had been as yet acquired.

Sponges are, however, only the lowliest of the Metazoa. To the next higher grade, the *Cœlentera*, belong a great multitude of animals that are no more familiar to the majority of people than are the sponges. This grade includes the little creatures that build the coral reefs in tropical seas. It also includes the jelly-fishes, sea-anemones and sea-mosses of our own shores.

One representative, called Hydra (Fig. 16 c), lives in fresh water pools, and may be taken as the introductory type for the Cœlentera. It has a long cylindrical body no thicker than a piece of thread, and is about one-quarter of an inch long. It is usually attached to some water weed by one end of the body called the foot. At the other end is the mouth around which are six slim tentacles arranged like the spokes of a wheel.

A thin slice cut across the body (Fig. 15 d) and examined under the microscope reveals the fact that the cylinder is hollow and is made up of two clearly-defined layers of cells. One layer lines the cavity of the body. In this all the cells are alike and all are concerned in the processes of digestion, either acting together by producing digestive fluid and pouring it into the central cavity of the body, or acting separately by engulfing the particles of food and digesting them as did the Amœba. The outer layer of cells is made up of several groups each acting collectively. One group is largely muscular in function, and by combined con-

traction or extension can shorten or lengthen the body as a whole or bend it this way and that. Another group is sensitive to outside influences, and in response to these transmits impulses to the muscular group, and thus co-ordinates the movements of the body to definite ends. Yet another group is reproductive in function. Such a group of cells acting together for the performance of some definite function is called a tissue.

This grouping or co-ordinating of cells for common action in the performance of a certain function carries the animal organisation to a higher grade than that exhibited by the sponges. Here is not merely differentiation of cells, but also of tissues.

As with Porifera so with Cœlentera each new individual is produced from one cell. Reproductive cells in all Metazoa are of two types. One that is very minute and active, is called the sperm or male cell. It consists mainly of nucleus and has very little ordinary protoplasm. The other is the ovum or female cell. This is much larger and inactive, and is richly provided with nutritive material. Before the egg cell can divide and become a new individual it must be fertilised. That is to say, a sperm cell must enter it, and the nuclei of the two cells must unite. When this has happened the cell begins to divide, and develops into another individual.

At one stage in development the cells are arranged in the form of a hollow sphere enclosed in one layer—this is the *blastula* stage. Later, one side of this becomes pushed in until the cavity is quite closed, and the whole has become a cup-shaped body called the *gastrula*,

which is made up of an inner and an outer layer of cells. The mouth of the cup narrows, and the cup elongates to the form of a jug. Around the margin of the mouth tentacles appear. Thus a new individual having the structure of a Hydra is produced.

Once more it is difficult to resist the temptation to believe that the Hydra and its allies have come from a one-celled ancestor, and that the stages in their descent are here reflected in the stages of individual development.

The earthworm is but a mediocre representative of a great and wonderfully varied group of animals classed as the *Annelida* that live in the sea. These, like the Porifera and Cœlentera, begin life as a single cell—the fertilised ovum. This by repeated division produces a blastula, which passes in turn into the gastrula. This, as already seen, consists essentially of two layers of cells, an outer called the *ectoderm*, and an inner, the *endoderm*. In the development of the annelids, however, a third group of cells, the *mesoderm*, puts in an appearance between the other two. The ectoderm produces the sensitive covering of the body (Fig. 15 f, g), the endoderm produces the lining of the digestive canal, the mesoderm does not, however, consist of a single layer but becomes a thick, bulky group of cells from which the main mass of the worm's body is derived—the muscles, the blood vessels, the organs for removing waste material from the blood, and the organs for manufacturing reproductive cells. These three layers or groups of cells are called the *germinal layers*. In the cœlentera there are only two germinal

GRADES OF ANIMAL STRUCTURE

layers. In the Annelida, and many other worm-like creatures not described, and in all the other Metazoa, to be dealt with later, there are three, but never more than three, germinal layers. There is no higher grade of fundamental structure known in the animal kingdom than this. All other animal types are but divergent modifications of this grade.

CHAPTER XVI

STYLES OF ANIMAL ARCHITECTURE

WITH each advance in grade of structure from the unicellular to the multicellular, from the possession of two to that of three fundamental tissue masses, the possibilities of differentiation of parts in structure and function greatly increase. Complex systems of organs for performing the primary functions of feeding, breathing, feeling, movement, excretion, reproduction, result from this differentiation. Up to this point in our survey of the animal kingdom, the differences which distinguish one large division or phylum from another have been predominantly progressive. From now onwards the greater complexity of organisation from which we start provides scope for much more numerous and divergent modifications. In order to illustrate this, four quite familiar animals—man, lobster, starfish and snail may be briefly considered.

Man is bilaterally symmetrical, that is to say, his body may be divided by a plane into two parts—the right and the left—one of which is exactly like the other, as it appears when seen reflected in a looking-glass. The lobster is also bilaterally symmetrical. So likewise is the lower part of a snail, but its upper part and shell baffle description in these terms. The starfish has not

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one but five planes of symmetry, in other words, it is radially symmetrical, and in this respect exhibits a marked divergence of general plan of structure from the other types.

In all four animals there is a hard skeleton or a shell. Man's skeleton is an internal framework which grows

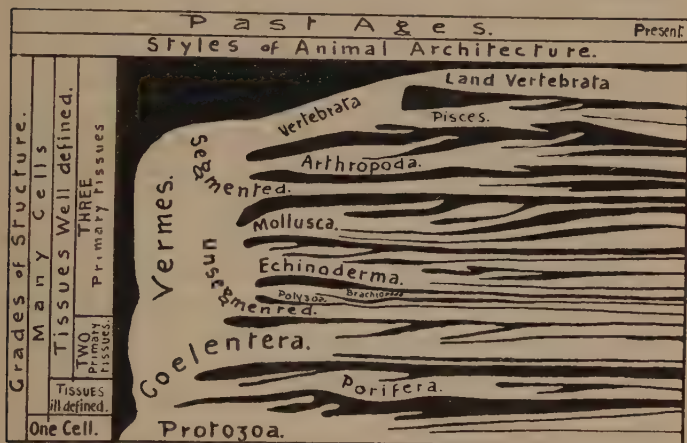


FIG. 16.—Diagram showing the major classificatory groups into which the animal kingdom is divided and their probable general relationship to one another according to time and affinity. Note the remarkable way in which the assemblage of animals living to-day contains representatives illustrative of all the main changes and advances which have been made in past ages. Thus present conditions grew out of and epitomise past history.

with him from birth to old age. The lobster's skeleton, popularly described as its shell, on the contrary, lies outside of, and completely encloses every part of its

body. Moreover, it does not grow with the lobster, but is shed like a suit of old clothes, and a new one is formed in its place. This process, called *ecdysis*, is repeated frequently during life. The starfish has a skeleton which at first sight seems to enclose the body as does that of the lobster. In actual fact, however, it completely underlies the very thin skin which covers the body. It is never shed but, like the human skeleton, grows as the animal grows. The snail's shell is something quite different from any of these. Its form does not recall that of the animal itself, it does not in any way provide support to the soft body, but is used merely as a haven of refuge in time of trouble.

Again consider the means of locomotion. Man has two, and only two pairs of limbs both of which are used for getting about from place to place, at least in early life. Each limb is built up on the same general plan of three main parts—upper limb, lower limb, hand or foot—flexibly joined together. The lobster has many pairs of limbs, each consisting of six or seven parts, and differing greatly in size and form from one another. At first sight the starfish seems to have no limbs, but if it be turned upside down a great multitude of soft finger-like processes, with concave sucker-like ends, will be seen upon the underside of each radius of the body. These are used singly and collectively by the animal for moving from place to place. The snail has neither limbs nor processes, it merely glides along upon the flattened under-surface of the body.

So, in like manner, one and then another set of organs and structures might be taken; but these examples

STYLES OF ANIMAL ARCHITECTURE

suffice to illustrate the fact of the existence of plans of structure which, though they serve the same functions, are quite different from one another, and exhibit comparable degrees of complexity.

There are numerous animals which are built upon the same general plan as man—e.g., horse, lizard, fish. All have the same symmetry, a body axis, two pairs of limbs, and an internal skeleton. Closer examination reveals many other details in which they resemble one another much more closely than they do the lobster, starfish or snail. They are, therefore, all regarded as related to one another and are classed together in one large subdivision or phylum of the animal kingdom called the *Vertebrata*.

In like manner, it may be shown that crabs, spiders, beetles, flies have more in common with lobsters than with other kinds of animals. They are on that account grouped together in another phylum—the *Arthropoda*.

The starfish represents the phylum *Echinoderma*, which also includes the sea urchins, sea cucumbers, stone lilies or encrinites.

The phylum *Mollusca*, to which the snail belongs, is a very large one. It includes the oysters, mussels, cockles, whelks, cuttlefish.

In addition to these large and more important subdivisions or phyla are several others whose representatives are smaller and less familiar. Each has its own peculiar plan of structure which differentiates it from those already considered. Among them may be mentioned the *Brachiopoda* or lamp shells, the *Polyzoa* or sea mats, and a number of interesting wormlike

types, other than the Annelida, which will not be discussed.

This system of classification is based on the assumption that similarity of structure is an indication of relationship. Those organisms which resemble one another are said to be related to one another. Those which differ greatly are regarded as being not closely related. The similarities and differences are discovered by comparing types with one another in details of structure, part with part, organ with organ. This is the method of comparative anatomy which will always provide the main foundations of facts for any true system of classification.

CHAPTER XVII

FOSSILS, THEIR ORIGIN AND USES

A FOSSIL is the whole or any portion of an animal or plant that has been preserved in the rocks. Impressions made by the feet or the skin which are similarly preserved are described as fossils even though no actual fragments of the organism itself are forthcoming. Generally, only the harder, more resistant portions, such as bones and shells are preserved. The soft, fleshy parts being very perishable decayed quickly, and have usually disappeared completely.

The study of fossils is, therefore, concerned with the living things of past ages. It is called *Palæontology* to distinguish it from *Biology*, which has for its province the study of the living things of the present. These two great branches of science are, however, mutually dependent upon and supplementary to one another.

The biologist has the great advantage that the whole organism is at his disposal. He is able, therefore, to work out in detail a complete account of its structure, life story and habits. At the same time he labours under the serious disadvantage that the living things of to-day are merely the last of the innumerable succession of generations that have peopled the earth for untold ages. Consequently many problems suggested by his studies have their final solution locked up in the records of the past ages.

The palæontologist, on the other hand, has for his material the fossil remains of those past generations. Unfortunately these are never complete even for one generation, for when a creature dies its soft or fleshy parts decay and perish rapidly, and only its hard parts, such as the shell or the skeleton, remain intact long enough to be buried in the mud, and subsequently sealed up in the rocks. Whilst, therefore, the biologist has before him a very complete record of only one generation, the palæontologist has an incomplete record of innumerable generations. The incompleteness of this record will be further realised when it is remembered that large portions of it have been destroyed, along with the rocks which contain it, by those very processes which, in carving the landscape, shatter the rocks and open the records to the enquiries of the investigator. Other large portions lie buried at depths which are only occasionally penetrated by mines, boreholes and railway tunnels. Even that fringe of these buried portions which lies nearest the surface is hidden from view under an almost continuous mantle of soil and vegetation. Only in a quarry here, or a sea cliff yonder are the rocks themselves exposed, and the fossils they contain accessible.

Any contemplation of the incompleteness of the record creates a sense of the hopelessness of the quest for a reasonably complete vision of the living panorama of the past. It must not, however, be forgotten that one good specimen reveals almost as much as a thousand. One tiger is for most purposes as good as a jungleful. Even the most ardent collector of fossils is content to leave behind a greater multitude of specimens than he takes away.

In nearly every phylum of the animal kingdom there are many types which have no hard parts and which, consequently, leave behind no record of their existence. Nevertheless exceptional circumstances do occur under which even they may be preserved. One of the most remarkable examples of this comes not, as would be expected, from the youngest, but from the oldest fossil-bearing rocks, from the Middle Cambrian shales of Mount St. Stephen in British Columbia. Here was discovered a rich assemblage of the remains of wholly soft-bodied animals, worms of various kinds, sea cucumbers closely resembling jellyfishes in form and flimsiness of consistency. Not only were the external features preserved but also many and very delicate details of internal structure. That discovery in addition to opening up broad fields of knowledge concerning life in Cambrian seas, creates hopeful anticipation of not less remarkable discoveries in rocks of other ages.

Fossils vary greatly in their value for the elucidation of biological problems. Thus the shell of a snail gives little or no idea of the structure of the animal that built it. On the other hand, the skeleton of a lobster reflects the structure of its owner in great detail. Other examples of this will be forthcoming in subsequent pages.

Valuable as fossils are to the biologist, they are not less so to the geologist. In the first place they furnish him with reliable indications of the conditions under which the rocks that enclose them were formed. Thus, for example, a rock which yields numerous fossil corals was in all probability formed under similar conditions to those in which corals live to-day—in the salty waters

of a clean, warm sea. On the other hand, if a slab of rock be marked with fossil footprints, it could not have been formed in the sea. It must have been formed upon the land at some place where water spread temporarily in times of flood, and then drained away leaving silt behind which remained soft long enough to receive the impress of the feet of passing land animals.

Fossils have, however, a further and even greater geological value as indicators of time. A coin bearing the superscription of an emperor is not more distinctive of the period when it was struck, than a fossil is of the age when it lived. The characters which make up a fossil are not less numerous than the features on the monarch's face, and the letters and figures which surround it. The greater the number of characters or peculiarities possessed by either coin or fossil, the greater are the chances against the same combination and arrangement of them being repeated at any other period. If, therefore, fossil shells and bones of closely similar, if not actually identical, pattern are found in rocks, at widely separated points on the earth's surface, these must have been formed when that particular pattern of organism existed. They must, therefore, be of the same age. Thus fossils furnish the only means whereby rocks of one region may be correlated with those of another that is far away. Fossils are, therefore, most delicate instruments for investigating and elucidating not only the story of past generations of living things, but also the time sequence of events in the physical history of the earth itself.

CHAPTER XVIII

THE STREAM OF LIFE THROUGH THE AGES

THE oldest fossil-bearing rocks in the British Isles were laid down at the opening of the Palæozoic period. The fossils they contain prove that already, at that exceedingly remote time, all grades of structure exhibited in the animal kingdom to-day were in existence ; and that, with the exception of the vertebrata, all the main styles of architecture had been differentiated from one another. This fact alone, when duly considered, creates in the mind a vivid impression of the great antiquity of life upon the earth.

This impression is confirmed by the discovery of beds of graphite among the most ancient of metamorphic rocks of the North-Western Highlands of Scotland. Graphite consists of carbon, which is the chief constituent in the tissues both of animals and plants. Apart from the activity of living substance there is no known process of Nature that piles up such masses of carbonaceous material as peat and coal. It is by the metamorphosis of such accumulations that layers of graphite have been produced. The existence of graphite in bulk among these metamorphic rocks may be taken then as a sure indication of the presence of living things in abundance on the globe when the deposits were being

laid down from which those rocks were derived. The evidence for the almost inconceivable antiquity of the metamorphic rocks of the Outer Hebrides and the North-Western Highlands, and therefore of this graphite, was indicated in an earlier chapter.

It is natural to enquire next what was the appearance, what were the peculiarities of the forms of life that lived during those vast Pre-Cambrian æons? Only a few fossils have as yet been found in rocks of Pre-Cambrian Age in any part of the world. Nor is it likely that many will be forthcoming in the future. Fossils, as already seen, are usually only the harder, more durable portions of the creatures they represent. But the production of such shells and skeletons was very far from being one of the first achievements of living things. On the contrary, all evidence points to it as a late acquirement in each phylum.

Under these circumstances light upon this problem must be sought in other directions. Such light may be indirectly obtained in two ways; one is by the study of the development of living forms. Take, for example, the Annelida. These are worms which, like the earth-worm, have a complicated body divided into a number of segments, lying one behind the other. This, as already seen, has attained the highest grade of structure, for it is produced from three germinal layers. In its development, however, it passes through all the lower grades from the one-celled grade upwards. The most reasonable explanation that has been given for this is, that the ancestors of the Annelida in successive ages had an adult structure conforming to these various

grades ; that, for example, there was a time when no Annelida, as we know them, existed, and their place was occupied by ancestral forms whose bodies consisted fundamentally of only two germinal layers. Inasmuch as all animals, whether Mollusca or Echinoderma, Arthropoda or Vertebrata, start life as a single cell, and develop through the two-layered to the three-layered grades, the presumption is that with them, as with the Annelida, there was one period in the earth's history when their ancestors had attained no higher grade than that with only two layers. In that far-off time the highest forms of life were no more advanced than the jellyfishes and sea anemones of to-day. A consideration of existing Cœlentera as a whole proves that, with this as its highest grade of structure, animal life could still be wonderfully varied and beautiful. The other indirect source of light upon the natural history of Pre-Cambrian seas is obtained by the comparative study of Palæozoic and later fossils, or even of present-day animals. The dominant arthropod in early Palæozoic times was the trilobite (Fig. 17 a). This creature bore a superficial resemblance to a woodlouse. It was flat in form, and roughly oval in outline. The body was made up of a number of segments one behind the other ; but the front or head-end was not segmented. In some trilobites the tail-end also was unsegmented. Each segment consisted of a middle and two side portions (Fig. 17 b). Attached to the underside of the middle was a pair of limbs, each with two branches, one of which looked like a feather and was used for swimming, the other was like the leg of a fly or crab,

and was used for walking. The continuous covering at the head-end also had a central and two side portions. Near the hind border of the central portion or glabella was a groove which crossed from side to side, and so made the hinder part look like the middle of a segment. Similar but not such complete grooves mark the front part of the glabella. In a few trilobites, including the

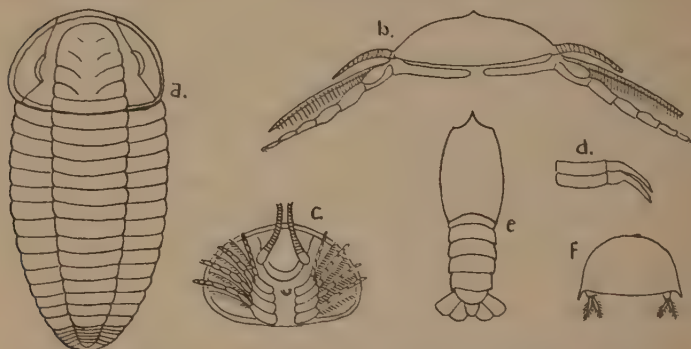


FIG. 17.—The structure of the trilobite (a to d) and lobster (e, f) compared.

a and e, upper view of whole body ; b and f, section across one segment ; c, underview of head ; d, diagram showing condition in trilobite having small lateral extensions of segments.

earliest one known, these grooves continue across, and give the glabella the appearance of a series of segments. On the underside of the head (Fig. 17 c) there are four pairs of limbs identical with those upon each segment. These two facts suggest the conclusion that the so-called head of a trilobite consists of a series of segments that have become united. There was, therefore, in all

probability an ancestor with a segmented head. The side portions of each segment in the body are longer and larger on the whole in the later than in the earlier trilobites. Indeed, in some of the latter, there are a few of the segments at the tail-end in which these side portions are absent and their place is taken by little spines. This progressive increase with advance in time suggests a decrease going backwards in time. The presumption is then that there was a Pre-Cambrian ancestor in which all segments were devoid of side extensions. This receives confirmation in the fact that such extensions are unknown among other Arthropoda (Fig. 17 e, f).

These and other facts point to a primitive creature living in Pre-Cambrian times that had an elongated body made up of segments devoid of lateral extensions, and ranging from the tip of the head to the end of the tail. Such a creature carries our conceptions of the ancestor of the trilobites, and indeed of all the arthropods, in the direction of an animal that had much in common with annelid worms. Some such creature as this must have been a familiar sight when as yet typical arthropods had not yet appeared in Pre-Cambrian waters. Thus may fancy feed on innumerable facts of anatomy and development, and wile away the time in re-peopling the unexplored waters of primeval seas.

Turning now to that section of time for which we have a more adequate fossil record, the chief impression produced by a general survey is one of increasing change. True the main styles of animal architecture were there

at the outset, but each of these was subjected to continual modification. Thus among arthropods, during early Palæozoic times, trilobites were everywhere dominant. During late Palæozoic times they disappeared and their place in the economy of the seas was taken by the crustacea, which to-day are as ubiquitous as were the trilobites. At first these crustacea were dressed in unfamiliar garbs, during the Mesozoic they became shrimplike and lobsterlike. At last, during the Cainozoic, genuine shrimps, lobsters, and even crabs appear.

In like manner as the Arthropoda changed so likewise did the Mollusca, the Echinoderma, and indeed all the other phyla of the animal kingdom. The combined result was that the face of living Nature changed from age to age. Even the fragmentary records in collections of fossils made from the rocks reflect the successive changes so well that the trained eye can, with a mere cursory glance, recognise the age which any given assortment represents.

One striking and unexpected fact emerges: it is that Nature never repeats herself. If she did fossils would have no value as indicators of time. The trilobites have gone, never to return, and the same is true for all the multifarious forms that the infinite fertility of Nature has produced.

CHAPTER XIX

RACIAL PROGRESS AND DECLINE

THE division of the animal kingdom into phyla corresponds with the existence of a number of easily distinguishable plans of structure. Each phylum is in its turn subdivided and re-subdivided into smaller and yet smaller divisions called respectively orders, families, genera and species. Thus, for example, among the Vertebrata there are a number of familiar animals such as the rabbit, hare, mouse, rat, and beaver, all of which possess peculiar gnawing teeth. These are classed together in the order *Rodentia*, to separate them from other similarly well-defined groups such as the weasels, cats, dogs, which are classed together in the order *Carnivora*. Within the order *Rodentia*, however, similar but smaller, clearly recognisable groups are found. Thus the beaver is quite easily distinguishable from the rats and mice, and these in their turn from the rabbits and hares. These three groups have the value of the classificatory division called the family and are named the *Castoridæ*, *Muridæ* and *Leporidæ* respectively. The *Muridæ* includes a multitude of other animals besides the mouse and the rat, such as the voles and lemmings. The mouse and rat, however, resemble one another more closely than they do any of these

other rodents, and are therefore grouped together in the genus *Mus*. Notwithstanding their close similarity the mouse and rat cannot be confused with one another because they exhibit constant differences in such less important features as size, colour and the like. This fact is expressed by saying that they are different species. The one is, therefore, called *musculus* and the other *rattus*. Every animal is given a double name made from that of its genus and species. Thus the Black Rat is called *Mus rattus*, and the House Mouse *Mus musculus*.

Such, in broad outline, is the system of classification used in dealing with the animals of this or of any previous age. It has been noted in previous pages that the animals of one age follow those of the previous age without a break between, that they are in fact descended from those. So the succession of living things has flowed on unbroken since the first appearance of life upon the globe until the present day.

This succession is, however, an ever-changing one. The characters of a species, though they seem so constant within the period of a human lifetime, change slowly with the passage of the much longer periods of geological time. The species of one age pass over into and become the quite different species of a later age. The descendants of this species in their turn take on the characters of yet another species at a yet later age. Such a series of species is called a *line of descent* or a *lineage* (Fig. 18). Every species that is alive to-day belongs to a separate lineage. Thus the mouse and the rat has each its own line of descent. There can be little

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doubt, however, that if there lay before us a complete collection of all the ancestors in these two lines we should find that, as we followed each series backwards in time, the ancestral forms would become more and yet more alike, that the lines would converge and, at some period of the past would unite in a common ancestor. The lineages for all the other species which belong to the genus *mus* would likewise converge and

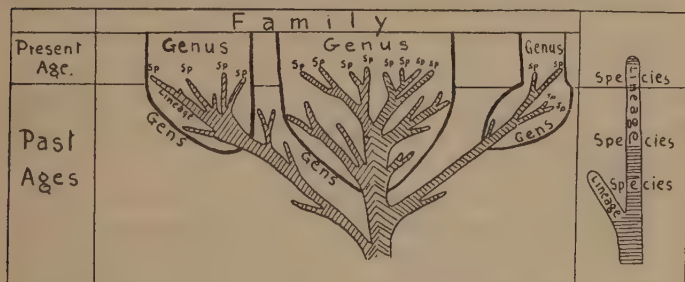


FIG. 18.—Diagram showing the relationship between the conceptions represented by such classificatory terms as genus and species which are based upon the study of living forms and the conceptions represented by such terms as gens and lineage, which are based upon the study of the succession of extinct forms.

unite later or sooner as the case might be. The geological history of a genus then resembles the small bough of a tree which started first as a single twig. As it grew it gave off shoots at irregular intervals, and each shoot in its turn behaved in like manner, until many twigs, or lineages were produced. At any point of time, such as the present, the tip of each twig is a species, and all the tips thus naturally grouped together on one portion of the tree form one genus. The whole bough

with its cluster of diverging lineages is a *gens*. The geological or racial history of a family or of any larger classificatory division is similarly made up of a cluster of diverging *gentes* and lineages. As yet, however, there is no recognised scheme of terminology for these minor and major clusters.

Though our knowledge of the details of lineages, *gentes* and larger racial histories is still very limited, it is sufficient for the recognition of certain phases which characterise them all. Each starts with a period of obscurity from which it emerges and enters upon a period of progress culminating in a period of acme; this is followed by a period of decline or gradual and ultimate extinction.

Generally but little is known about a race during its period of obscurity. There are various reasons for this. At its inception the members of a new race are limited in distribution to one area on the earth's surface. Not infrequently the rocks formed in that one area are as yet unexplored, or are for various reasons inaccessible. Again the individuals are usually small as compared with the other races that happen to be dominant, and on that account are easily overlooked. For some races the formation of skeletons is confined to the later stages in their history, and consequently the forerunners are not preserved in the fossil state except under very special circumstances. Examples illustrating these points will be forthcoming later.

Eventually the race emerges from its obscurity, it spreads into other areas, or enters fresh habitats or conditions. New modifications of structure and adap-

tions to environment appear. Thus the progressive phase sets in. This and later phases of racial history may be illustrated by a consideration of the Trilobites, for it is just at this stage that our knowledge of them begins. Throughout the whole of Cambrian times the Trilobites progressed, steadily producing new lineages and gentes, a few of which, however, became extinct. The total number, however, increased, and reached a maximum during the Ordovician, as the middle of the Protozoic is called. This, then, was the time of acme for the Trilobites. They ranged through the waters of every epicontinental sea. They occupied every nook and cranny in the economy of marine nature. The majority lived upon the sea floor, here in the gloom of muddy waters, there in the sunlit depths of clear water where sea weeds and many other forms of life abounded. Some burrowed in the mud, others swam rapidly in the open sea, whilst others floated lazily in the sunshine at the surface. Never before or afterwards were Trilobites so varied in form and adaptation, or their genera and species so numerous. At this time they exhibited their greatest range in size from tiny forms only the fraction of an inch long to large ones having a length of as much as two feet.

At the close of the Ordovician, signs of waning virility were manifested, and during the Silurian or later Protozoic period, first one and then another lineage stopped developing with the result that whole gentes came to an end. Out of a total of nearly two dozen known families of Trilobites only six existed in the early Deutozoic. Only two, possibly three, genera are

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known to have lived in late Deutozoic waters, and these disappeared before the end of this period. This period of decline was, therefore, a long one, lasting, as it did, from the end of the Ordovician to the close of the

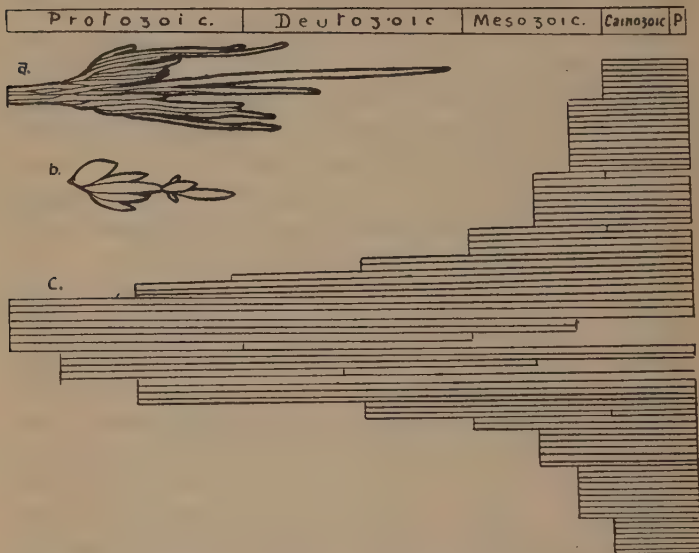


FIG. 19.—Diagrams illustrating the racial histories of three great groups of animals. a, trilobites ; b, graptolites ; c, gastropods. In each case the narrow spaces enclosed by lines represent families, the length of each space shows the range of existence of each family through time. Note in all three cases the increase in numbers of families up to a time of maximum, followed by a decrease in number as the race declines and various families become extinct. Note also the different rates at which these changes take place in different groups of animals.

Palæozoic. It is customary to speak of the Trilobites as having become extinct at this point in time. It

should, however, be borne in mind that, as shown above, for the race as a whole, extinction was a long, slow process which commenced at the close of the Ordovician and attained its culmination in late carboniferous times.

The study of the fossil remains of creatures belonging to other subdivisions of the animal kingdom reveals the fact that there is no uniformity in the rate at which any particular animal type progresses and declines. Take, for example, the Gastropods, the subdivision which contains the snails, whelks and periwinkles. Gastropods were already in existence in the seas at the opening of the Palæozoic period (Fig. 19 b). As with Trilobites, those rocks which contain the record of their origin have not yet been discovered. Throughout the age of Trilobites, the Gastropods still remained in comparative obscurity. Nevertheless they were making steady, though very slow progress. This progress continued whilst Trilobites were declining. Throughout the long ages that have elapsed since the Trilobites disappeared, they have continued to progress with the result that to-day they are in their acme. The racial progress of the Gastropods has, therefore, been so slow that it has continued across almost the whole of geological time.

How different was it with the Graptolites (Fig. 19 b)—minute cœlentëra that lived together in great numbers forming colonies. These resembled in many respects the present-day sea mosses. Graptolites appeared upon the scene at the opening of the Ordovician, just when Trilobites were approaching their acme. They seem to have been floating organisms and consequently drifted

with extraordinary rapidity to all parts of the world. With comparable rapidity they romped through their racial history. No sooner had a new type been produced and distributed than it was superseded. Whilst as yet Trilobites were in their heyday the Graptolites experienced an extraordinary mortality, and lineage followed lineage through rapid decline to final extinction. Just when all seemed lost one of these, represented by the genus *Diplograptus*, seemed to experience an unexplained accession to virility. The race became, as it were, rejuvenated, and Graptolites were once more produced from it in vast numbers and great variety. This revival lasted but a short while. Before the glory of the Trilobites in their heyday had begun definitely to wane the Graptolites once more fell into rapid decline, and became completely extinct before the close of the Silurian period.

CHAPTER XX

THE INTERLACING OF LINES OF DESCENT

IN all that has gone before the idea of relationship of one type of organism to another has underlain our discussion of living things. It has been frankly assumed that similarity of structure implied community of ancestry. As long as the study is confined to creatures living to-day such similarity both in youth and maturity is the only criterion of affinity. When, however, fossil records are taken into account it may be expected that sooner or later the actual descent from the common ancestor may be traced and relationship demonstrated.

In discussing such problems there is, however, a tendency to slip automatically into the methods of the historian with his genealogical tables of kings and queens and in so doing to lose sight of nine-tenths of the truth. Forgetting that there are such irrelevant phenomena as thrones and inherited wealth, it becomes necessary to look at the facts as they are. Start then, with a father and mother and, say, three children. The latter, because they have the same parents, are blood relations to one another, or, to use the recognised terminology, they are genetically related.

The children grow up, marry and have families of their own. They were brothers and sisters, their

children are merely cousins. The process is repeated until after quite a small number of generations there may be as many as a thousand descendants from the original father and mother. Any one of these may have several brothers and sisters, a score of cousins, two

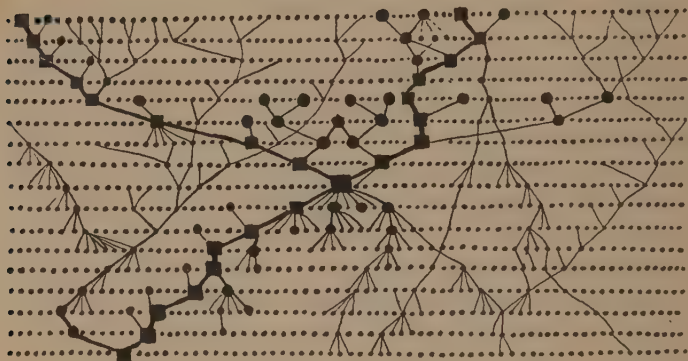


FIG. 20.—Diagram illustrating the extraordinary complexity of a so-called "lineage." Each horizontal row of dots represents one generation of individuals in a lineage. The top row is the last generation. The square dots connected by thick lines represent the historian's direct line of descent (historian's lineage). The large round dots are other individuals of sufficient importance for him to mention. The thin lines connecting dots represent a very small number of the lines of descent. If lines representing all lines of descent were inserted a very complicated network of interlacing lines would result. This network is the palæontologist's "lineage" or "line of descent." In the study of hereditary problems it must be remembered that all individuals of all generations in the network are concerned in the transmission of hereditary characters, and that chances are against the precise combination of characters in different stages of evolution ever being exactly the same for any two individuals. Marked differences between members of one generation are called "variations." Marked differences between members of successive generations are called "transients" (mutations of Waagen).

score of second cousins, and a host of distant relatives, most of them complete strangers, and their relationship unrealised or quite forgotten. A genealogical tree showing all these people would usually be regarded as remarkably complete, with its triangular form having a pair of people at the top and a multitude at the base. Nevertheless, it omits nine-tenths of the salient facts. Thus, for example, working backwards from the original pair, it will be found that each of these had two parents—total four, four grandparents—total eight, possibly sixteen great-grandparents and so on up through the centuries until a thousand years ago the ancestors could be reckoned by millions. For any Englishman of to-day one of those millions was, in all probability, William the Conqueror.

The genealogical table of one person is like two triangles joined together at the apices. But even now the picture is still incomplete. What is true for that individual is true for everyone of his contemporaries, predecessors and successors. The triangles for each overlap those for many others. The complete record of descent is like a piece of lace net, a complex nexus of intertwining strands, which travel hither and thither as the network unrolls. All the members of such a network of descent belong to the same stock. The terms lineage or line of descent when used in the discussion of biological and palæontological problems are used then in a quite different sense from that of the historian for they signify not a single line but an elongated network of complicated pattern.

All animals and plants, belonging to the same stock

or lineage, that are living at the same time are regarded as genetically related, and are said to belong to the same species. It is characteristic of the members of a species that they are fertile to one another, that is to say, that they can breed and have young.

The detailed study of the offspring and descendants from a single pair of animals or plants can be made only by the experimental biologist in his laboratory. Limitations of time and space, however, prevent him from carrying his experiments to many generations. Nevertheless the results of his work are essential to an understanding of the intertwining strands which make up the nexus of descent.

The student of organisms as they occur in Nature or as they are found in the fossil state can deal only with the mass of individuals which make up a species. True he handles isolated specimens, but their detailed relationship to one another is of necessity unknown to him. He can only regard them as representative members of a stock whose structural peculiarities and history provide him with a theme.

CHAPTER XXI

THE LINK BETWEEN THE GENERATIONS

IT has already been noticed that every organism commences its individual life as a single cell, the fertilised egg. This by repeated division gives rise to all the cells, tissues and organs which ultimately make up the creature's body. Within this body there is one organ, a group of cells, which is concerned in the production of the germ cells or gametes, called in the case of the male the sperm cells or male gametes, and in the female the ova or female gametes. A few ova become fertilised, a few sperms fertilise ova, these alone have fulfilled their function and become the means of giving rise to new organisms. Many germ cells, however, never have an opportunity to function, and they along with all other parts of the body, die and perish.

Between the present generation and the last, and indeed all the generations that have gone before, there has been a connecting thread of protoplasm contained in the effective germ cells that have produced them. From the first formless creature that lived in the primordial seas this thin thread has stretched unbroken from parent to offspring, through the ages as they rolled by, and linked them all to the shapely, highly-organised baby that breathed air for the first time to-day. This thread is called the *germplasm*, to distinguish it from each body or *soma* that is produced

from it. The structure and constitution of germplasm may be studied by direct observation upon the germ cell with the aid of the microscope. Great strides have been made in this important branch of scientific enquiry; nevertheless there is much that seems to be beyond the power of the microscope to reveal, and that can only be indirectly inferred by means of a careful study of the soma. This latter method of approaching the problem is based upon the assumption that the various features which are exhibited during development and in maturity by any individual must have some counterpart in the minute, even ultra-microscopic structure of the germplasm. In no other way does it seem possible to explain why the lion's cub grows up and becomes a lion that is almost the exact counterpart of its parent.

Much interesting light has been thrown upon this subject as the result of a method of experimentation which was initiated by Gregor Mendel, a monk, who lived in the monastery at Brunn. The results of his experiments were published in 1865, but were overlooked until 1900, when their importance was first realised. The experiments were performed upon two varieties of edible peas, one tall, the other short. The first step taken was to cross-fertilise the flowers of these two types, that is to say, the pollen of one was used for fertilising the ovules of the other. The seeds thus produced were sown and grew into what may be called the first filial generation (F_1); all the members of which were tall! The quality of shortness had apparently disappeared. Each flower borne by this first generation of peas was then fertilised by means

of its own pollen. The plants which grew from the resultant seeds were the second filial generation (F_2). Of these 75 per cent. were tall and 25 per cent. were short. Evidently the quality of shortness had not been suppressed in (F_1), it had only been temporarily overshadowed. Tallness was therefore described as being dominant, and shortness, recessive. The flowers borne by this second generation were in like manner self-fertilised and the third generation (F_3) was produced. This process was repeated for several generations. Those plants derived from the 25 per cent. shorts were all short. As long as their flowers were self-fertilised, only shorts were produced. Evidently the quality of tallness had been eliminated from them. Similarly, 25 per cent. of the (F_2) generation turned out to be pure tall, from which the quality of shortness had been quite eliminated. The remaining 50 per cent. were still mixed in constitution, but they yielded in successive generations pure tall, pure short, and mixed tall and short in the proportions of 25, 25, 50.

From these experiments several interesting conclusions may be drawn. In the first place, they provide experimental support for the assumption that the characters of the soma are definitely represented by something in the germplasm. So then even the palæontologist, though he cannot possibly experiment in like manner with his fossils, may, by tracing the changes which the soma of organisms has undergone from age to age, hope to do something towards elucidating the structure and properties of the germplasm which produced them.

These experiments also show that the something in the germ cell which represents a character in the adult is a very stable and independent entity. Within the limits of present experimentation it may be temporarily overshadowed but cannot be made to fuse with or be merged into another.

Still more fascinating results have been arrived at by later experimenters in dealing with two pairs of characters, e.g., tallness and shortness, purpleness and whiteness of flowers. Starting with tall peas having purple flowers and short ones with white flowers there have been produced not only pure strains like the original parents but also pure strains of tall peas with white flowers and short ones with purple flowers. Evidently the characters are so independent that they may be transferred from one stock to another and consequently new varieties may be produced.

Experiments of this kind have been repeated for so many different kinds of plants and animals that no uncertainty about the validity of these conclusions remains.

So, then, a living organism is a combination of independent characters, and the germplasm a combination of corresponding tendencies which under favourable conditions may be shuffled from one stock to another. There appear to be, however, strict limits to the shuffling, set by the degree of relationship that exists between the stocks involved. Various breeds of horses are fertile to one another and produce fertile offspring, but the mule which is a cross between the ass and the mare is itself sterile.

CHAPTER XXII

THE GROWTH OF A SPECIES

It has been shown in the preceding pages that an individual animal or plant is a combination of characters or of units that has been transmitted to it from parents and predecessors by means of the germplasm in the germ cell. These characters are therefore said to have been inherited, and the combined phenomena involved are spoken of collectively as *heredity*. The independent characters, and the tendencies of which they are the physical expression, may be called heritable units. If the problems of heredity as they concern the whole organism are to be solved, careful attention must be given to the study of the units, which in combination make up the organism. For this purpose, a detailed study must now be made of the structure, development and geological history of a simple fossil coral called *Zaphrentis*. This will be followed in the next chapter by a less detailed study of other corals.

Zaphrentis is common in the Carboniferous rocks. It is conical and slightly curved in shape (Fig. 21 a). At its broad end it is hollowed out into a shallow cup or *calyx*. The floor of the cup is formed by a thin plate, the *tabula*. Rising from this floor and projecting radially inwards from the sides of the cup are a number of thin vertical plates, the *septa*. The covering which envelops the whole coral and forms a wall round the calyx consists of a thin outer layer, the *epitheca*, and a

thick inner layer, the *theca*. These four things, epitheca, theca, tabula and septum, like the bricks and beams of a house, are the units used in building up this coral. Many other corals differ from this one mainly as houses differ from one another, namely, in the proportions and arrangements of these structural units.

The arrangements and proportions which characterise *Zaphrentis* are as follows. The theca is conical, the

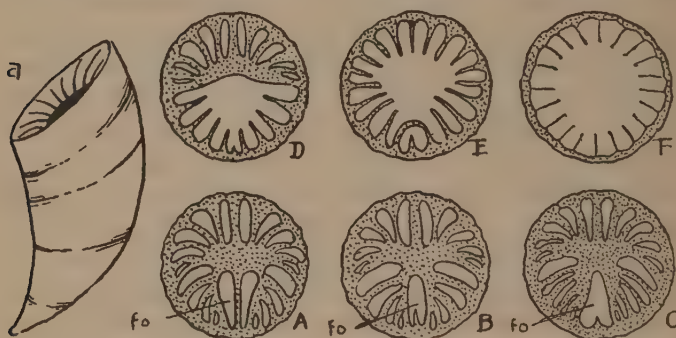


FIG. 21.—Evolution of the coral *Zaphrentis delanouei* (after Carruthers).

a, side view of the complete coral.

A to F, sections across examples found in rocks of different levels ; A, from the lowest or oldest level ; F, from highest or youngest level. Between A and F an unbroken or continuous series of changes was found. A to F represent easily distinguishable points in the series, such points are called "transients" (mutations of Waagen). fo = fossula.

tabulæ are slightly convex upwards, the septa are nearly radially arranged (Fig. 21 A) and are in four groups. Within each group the septa show a progressive decrease in size and are united in fan fashion. The spaces between the groups are called fossulæ and corres-

pond with more or less clearly-defined depressions on the surface of the tabula.

Each specimen was the life-work of one coral polype, a hydralike creature belonging to the Coelentera. The polype rested with the lower end of its body in the calyx, and secreted lime in the form of minute pellets, which were deposited along the edges and on the surfaces of the theca and septa, the thickness and height of which increased accordingly. From time to time the polype, while remaining attached to the theca and septa, detached itself from the underlying tabula and secreted another at a higher level. Meanwhile, the polype increased in size, and consequently the theca increased in calibre.

It is evident that the point of the conical coral, which in life projected downwards, was made when the polype was very young and tiny ; whilst the parts immediately adjoining the calyx were formed only just before the creature died. By cutting thin slices (Fig. 21 A-F) across the coral at different levels between the point and the cup, and examining them under the microscope, it is possible to discover the changes which took place during its development.

There are many different species belonging to the genus *Zaphrentis*, but attention will be confined to only one, *Zaphrentis delanouei*. In one investigation many hundreds of specimens of this species were collected from the Lower Carboniferous rocks of the Midland valley of Scotland. The total thickness of these rocks was 5,000 feet. They therefore represent the passage of a considerable length of time, during which

the life conditions were subject to variation. Sometimes these were favourable to the growth of corals, and are represented by the layers of limestone, in which the corals are preserved.

The specimens collected from the lower layers of limestones exhibited many small differences from one another. Such differences are to be expected when it is remembered how many possibilities there are of difference in angle and curvature of the theca, in number and length of septa, flatness or convexity of tabula. These are indeed so numerous that the chances are all against any two specimens being absolutely identical in every detail. The most striking and easily noted difference was found in the shape of the main fossula. In some the sides of the fossula converged towards the theca (Fig. 21 A, fo.), in others they were parallel (Fig. 21 B, fo.), in yet others they diverged (Fig. 21 C, fo.). The specimens exhibiting these types of fossulae are described as variations or varieties of the species *Z. delanouei*. Between them, however, every gradation was found, but for the purposes of discussion these three may be picked out and labelled A, B, C, and the rest be grouped around them. The percentage numbers of specimens referable to each grade were A 69, B 30, C 1. Variation A was evidently predominant. Similar differences are exhibited by the members of all species of animals and plants living during the same period of time. Such differences also distinguish parents and offspring, for a child is never exactly like its parent. Whilst, therefore, the offspring tends to inherit the parental characters as a whole, they tend also to exhibit

differences. These two opposite tendencies are referred to as *Heredity* and *Variation* respectively.

The specimens collected from limestones two thousand feet higher in the series exhibited the same grades of variation, and also an additional grade which may be labelled D (Fig. 21 D). The percentage numbers in this case were as follows: A 7, B 3, C 69, D 28. The predominance had now passed to C. One thousand feet higher grade A was unrepresented, having by this time become extinct. The percentage numbers for the others were B 3, C 16, D 83. At the topmost level, B was also missing, and the figures for C and D were 5 and 95 respectively.

The combined differences between A at the lowest level and D at the highest were so great that, if accidents of preservation and collection had allowed the discovery merely of odd specimens of these two, they would undoubtedly have been treated as at least distinct species by many if not all collectors. In the multitude of specimens collected the series was continuous in gradation from A to D.

A consideration of the distribution of the grades showed that the whole series from A to D is not completely represented at any one level. On the contrary, the range of variation in each case is limited to only a section of the whole series. The range, however, changes from level to level, that is to say, with the passage of time. Furthermore, the variation that is dominant also changes, shifting as it does so systematically from one end of the series to the other, from A to D. Thus a regular and definite change in

the structure of this coral takes place with the passage of time. Each of the definitely recognised stages in such a time series is called a *transient* (=Mutations of Waagen, not of De Vries). Variations are contemporaneous, Transients are successive in time. Variations mark the differences exhibited in a cross-section of a lineage or network of descent ; Transients those along its length.

When the development of an individual belonging to transient C is studied, it is found that the arrangements and proportions of its parts in early youth are those exhibited by the adult of transient A, which obviously belongs to the ancestral stock of C. The same is true also for the other transients. No better evidence could be forthcoming to show that the main phases in the history of a race really are inherited and expressed in the development of an individual, for in this case the two records have been placed side by side.

The gradual evolutionary change just described for this series of transients A to D of the coral *Zaphrentis delanoueï*, reflects corresponding changes in the long succession of polypes which secreted the specimens that were examined. Each polype started life as a minute germ. The characters shown by the adult polype were, in some way not yet understood, determined by the ultimate structure or constitution of that germ. If the characters of successive generations of adult polypes change, the constitution of the germ substance or germ-plasm, which is handed on from parent to offspring, must likewise have undergone some corresponding change. In other words, the evidence of fossils shows that germplasm also evolves.

CHAPTER XXIII

THE GROWTH OF COMPLEXITY IN NATURE

PALÆOZOIC corals have not all precisely the same parts and arrangement and proportion of parts as have been described for *Zaphrentis*. This may be illustrated by a brief consideration of several other genera of corals that lived in the Carboniferous seas.

One of the commonest of these is *Lithostrotion* (Fig. 22 a), a compound or branching coral. Each branch is the lifework of one polype and in this respect is comparable with *Zaphrentis*. In addition to having the epitheca, theca, septa and tabulæ, it has two other structural units, viz., a *columella* and *dissepiments*. The former is a solid rod which forms a vertical axis down the centre of the coral. The latter are short nearly vertical plates uniting the outer edges of the septa with one another and with the theca.

Another genus, *Dibunophyllum* (Fig. 22 b), like *Zaphrentis*, did not grow in colonies. It has the same structural elements as *Lithostrotion* except that its columella is flattened like a very thin lath. In addition, however, it had two more units, viz., *tabellæ* and *lamellæ*, resembling dissepiments and septa, but clustered round the columella instead of being arranged on the inside of the theca. The arrangement of these new elements

around the columella gives to the centre of the coral, as seen in a thin slice, the appearance of a spider's web.

These seven structural units, epitheca, theca, septum, tabula, columella, lamella, tabella, provide practically all the building materials out of which the numerous and diverse corals that lived in Palæozoic waters were constructed. In many of the more complex corals all units were used. In the less complex, as for example *Zaphrentis*, this was not the case. In such simple corals the same few units were not always used. In

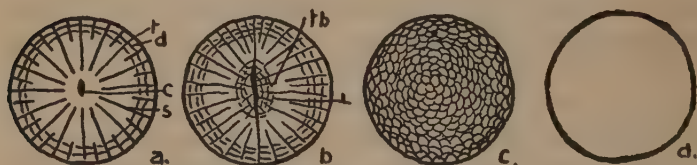


FIG. 22.—Sections across widely different kinds of fossil corals. a, lithostrotion; b, dibunophyllum; c, cystiphyllum; d, favosites. These and other corals are constructed out of the following limited number of structural elements: t=theca, d=dissepiment, s=septum, c=columella, tb=tabella, L=lamella, and "tabula," not shown in these sections.

illustration of this, compare with *Zaphrentis* two other genera, *Cystiphyllum* (Fig. 22 c) and *Favosites* (Fig. 22 d). The former is a Silurian coral built up only of epitheca and dissepiments. The latter lived throughout the Silurian and Deutozoic and consisted only of epitheca, theca and tabulæ.

These facts prove that the presence of any one structural unit is not necessarily dependent upon the presence of another. These units are, so to speak,

independent of one another, and for that reason they may occur together in many different combinations. Thus one organism differs from another not in some mystic and indefinable way, but frequently in being made up of different combinations of a limited number of structural units. That each structural unit is an independent entity is emphasised when the proportionate sizes and numbers of each in different corals are taken into account. Thus a theca may be obtusely or acutely conical or even cylindrical. The dissepiments may form one or many rows arranged concentrically with the theca. In corals of the same size, septa may be few or many; they may extend from the theca to the centre of the coral, or be confined to the margin; they may be arranged in fan fashion, or radially. The septum may be long or short quite irrespective of whether the rows of dissepiments are many, few or absent, or whether the theca is conical or cylindrical.

A comparison of the proportions and arrangements of the septa in the transiential series of *Zaphrentis delanouei* (see Fig. 21, A-F), and in the developmental stages of an individual of the same species, shows that these differences merge into one another to form a series. Thus, for example, the withdrawal of the inner end of the septa from the centre is not brought about by a sudden jump, but gradually, both in the evolution of the lineage and the development of the individual.

Each structural unit then has its own series of changes in proportion through which it passes in either development or evolution; that is to say, it has its own developmental and evolutionary history.

This fact greatly increases the possibilities of variety of structure in the complete coral. Thus, for example, if there are only three distinct units, viz., K, L, M, present, and each has five distinct stages in its evolutionary history, viz., K_{1-5} , L_{1-5} , M_{1-5} , the combination may be $K_1 L_3 M_2$, or $K_2 L_5 M_3$, and so on.

Further possibilities of variety of structure are introduced by the fact that the arrangement of units of the same kind has a developmental history also. Thus septa are always present in appreciable numbers. Their arrangement changes from the four fanlike groups to being quite radial. This change is exhibited not only in *Zaphrentis Delanoueï*, but in many other Palæozoic corals.

Thus it comes about that, with a basis of only a few structural units, and of a limited range of size and proportion of these, an almost infinite variety of structure and pattern is conceivable. Because these units are independent, and may pass through developmental changes independently of other units, this infinite variety is not only conceivable but possible. A careful examination of a number of specimens of either living or extinct animals proves not only that this is possible, but that it finds actual expression in nature.

But whilst the developmental changes that may take place in the proportion and arrangement of like units form a series, which though limited in range, is continuous, like time and space ; it does not follow that the combinations themselves as they follow one another from parent to offspring will form an equally continuous series.

Suppose, for example, that at a certain time there existed such a continuous series of combinations as $K_1 L_1 M_1$, $K_2 L_2 M_2$, $K_3 L_3 M_3$. These may be regarded as variations of the same species, and therefore capable of interbreeding with one another. As shown by Mendelian experimentation, it is possible for characters to be interchanged in the process of breeding, and therefore for such combinations to arise as $K_1 L_3 M_2$, $K_2 L_2 M_1$, $K_3 L_1 M_3$. These no longer form a continuous series, and thus "sports" or "saltations" or Mutations (De Vries), may appear.

In all discussions upon problems of Heredity and Variation, care should be taken to keep clearly in mind this distinction between structural units, on the one hand, and combinations of structural unit, on the other. Most variational studies are upon isolated structural peculiarities. Thus, for example, in the next chapter, two isolated peculiarities of the shell of *Gryphæa* are considered, viz., curvature and area of attachment. It is, of course, a convenience to refer to the successive stages by means of specific and variational names. This, however, leads to confusion of thought, when it is not realised that in doing this the phenomena of units are being discussed in the language of combinations. Such confusion is illustrated by the widely diverging meanings attached to the word "mutation"; and by the apparently irreconcilable positions of those who hold that evolution is continuous, and of those who hold that it is discontinuous. The former really have in mind the history of structural units; the latter, the history of combinations.

CHAPTER XXIV

INDIVIDUAL AND RACIAL DEVELOPMENT

IT has already been noticed that there is a general resemblance between the development of the individual and the history of the race to which it belongs. That there should be such a resemblance is not surprising when it is remembered that the starting point in both cases is the single cell, and that the finishing point for both is the individual in question. It is not to be expected, however, that the developmental record should be so complete that it should repeat all the details of all the stages in racial history. The mere question of time determines this, for whilst the one, even in slowly growing creatures, does not last longer than three score years and ten, the other spans eras of untold length. It is, however, only by a consideration of observed facts that the propriety of such expectations can be established. Some progress can be made in this direction by comparing the stages in development with the structure and development of individuals of lower grade. Traces of this method of approach will be found above in Chapter XV. It has, however, the very serious disadvantage that a lower type living to-day cannot be regarded as ancestral to another that is, so to speak, living next door. The lower type may have

descended from the same ancestor and, for that reason, have certain features in common with the higher type ; but in most respects it is a modified, often a much modified, descendant of that common ancestor. The fossil record, imperfect as it may be, alone provides samples of the actual members of the "lineage" to which the individual that is being studied belongs. In order, therefore, to put to the test the suggestion that the development of an individual exhibits the main stages through which its lineage has passed, and to discover some of the principles which govern development, a detailed study of a lineage must now be undertaken.

One of the most abundant of fossils is the genus *Gryphaea*, and one of its most characteristic species is *incurva*. This is found in the clays of the Lower Lias, a group of strata representing an early portion of the middle of the Mesozoic period.

Gryphaea belongs to the same great division of the Mollusca as such forms as the cockle, oyster and mussel. These are all characterised by a shell made up of two parts or valves joined together by an elastic ligament which serves the purposes of a hinge. Each valve is built up by the addition of thin films of lime to the inner surface. As the animal within the shell grows, the films of lime made by it become more extensive and spread beyond the margins of those which have been laid down previously. This overlap is most marked along the free margins of the shell ; along the hinge margin it is negligible. The edges of these films appear upon the outer surface of the fully-grown shell as a

series of almost concentric lines, very closely crowded near the hinge, but more or less widely spaced elsewhere. These are called "lines of growth." In normally shaped bivalves each valve exhibits near the hinge line a marked bulge, called the Umbo. This forms the rather excentrically placed centre of the growth lines. Here, then, is that part of the shell which was formed in early life. As the eye travels outwards from the apex of the umbo towards the margin of the shell, and notes the changing form of the growth lines, it is at the same time surveying the successive stages in the growth of the individual shell.

Turning now from the shell of a normal bivalve to that of *Gryphæa incurva* (Fig. 23), it is at once evident that in this one valve, which corresponds with the right valve in normal times, is small and flat. The left valve, on the other hand, is enormously enlarged, and its umbo is so prominent that it curves over and touches or nearly touches the outside surface of the right valve. When the shell is broken, or cut across, it is seen that the left valve is very thick, and consists of a succession of thick films. An examination of the umbones of the two valves shows that they were nearly equal in early youth, and that the left was only a little more convex than the right. As growth proceeded, however, much more lime was added to the inner surface of the left than the right, and this resulted in a progressive curling over of the left umbo throughout life.

Many specimens of this fossil were collected from successive levels in the Lower Liassic strata. A careful

INDIVIDUAL AND RACIAL DEVELOPMENT

study was made of the variations which occurred at each level, and the percentages of these were worked out. Here again, as with *Zaphrentis delanouei*, it was found that a continuous series of transients—call them 1-10—had arisen, ranging from small oysters of the type called *Ostræa liassica* (Fig. 23, 2), to extreme cases of *Gryphæa incurva* in which the left umbo curved over to such a degree that it locked the right valve effectively, and the death of the creature within the shell must have ensued. Here again representatives



FIG. 23.—The evolution of *Gryphæa* from *Ostræa* (after Trueman). 9 *Gryphæa incurva* fully developed. 2, 4, 6, three transients leading up to *gryphæa incurva*.

2 Very primitive transient. Thick line shows extent of area by which it was attached.

4 An early transient in which area of attachment is reduced, and the shell has begun to coil.

6 A later transient in which the area of attachment has almost disappeared and the shell has coiled through 180°.

a in the diagram represents very late transient, without area of attachment, coiling has taken place through about 450°.

The transients of previous ages become the variations of any one age.

In the diagram the black graphs represent the range of variation in degrees of coiling at successive levels, a being the lowest and oldest, e, the highest and youngest. The height of each part of a graph corresponds with the number of individuals showing each variation at each level.

Though transient No. 10 differs from No. 1, the evolution from 1 to 10 is continuous, that is to say, there is no break in the sequence of changes.

of only a portion (e.g., 1-5) of the series coexisted at the same time. The portions belonging to successive levels overlapped, thus transients 1-5 occurred at one level, 3-7 at another, 5-9 at yet another, and so on. Their dominant variation likewise changed progressively (Fig. 23, diagram) from level to level and, therefore, with the passage of time, from the lower to the higher terms of the series. Here, then, is a lineage the details of which are well known.

In the earliest and lowest terms of the series, viz., 1, 2, the left valve is only slightly more convex than the right (Fig. 23, 2). Its umbo is obscured owing to the fact that throughout life this little oyster-like form was attached by this part of the shell to stones and other objects. The mode of attachment was by cementation of the umbonal area to the sea floor. In the transiental stages 3 and 4, this area of attachment was relatively smaller (Fig. 23, 4), and the left valve showed distinct signs of curvature. In stage 6 (Fig. 23, 6) the area of attachment was so small that it is evident the shell was fastened to the sea floor for only a short time during early life. In later life it broke loose from its attachment and became free. In early life the shell, at stage 6, whilst still very small, is a replica of the adult shell as it appeared in stages 2 and 3. That is to say, the degree of development attained at the end of life in stage 2 was reached in stage 6, whilst the individual was still very young. Again the degrees of curvature exhibited by stages 3 and 4 are passed through whilst the individual of stage 6 is still young. Evidently there is not merely a repetition of stages (palingenesis)

there is speeding up or hastening of development (tachygenesis) which leaves the individual time during the later stages to continue developing to a yet more advanced stage. Thus it comes about that in its old age the individual anticipates the degree of curvature which will characterise the mature adult of the next transiental stage.

But whilst there has been this progressive increase of curvature, there has been a retrogressive decrease in the area of attachment. From stage 6 onwards there is no trace of this, and the individual is now free throughout life. The attached stage in the early ancestral history has therefore been skipped or cut out of the developmental record (lipopalingenesis). This supplies yet another proof of the mutual independence of characters, for the omission of this feature is not accompanied by any disturbance of the development and evolution of others.

The developmental record may be further falsified by the insertion of features never possessed by ancestors (coenogenesis).

The life story of *Gryphæa* does not, unfortunately, illustrate this. As will be seen in Chapter XXVI, the ancestors of the frog were fishes. Fishes breathe by means of gills hidden away in holes in the side of the throat. A tadpole represents the fish stage in the evolution of the frogs. Whilst it possesses gills like those of the fishes, it has, during its own evolution as a tadpole, acquired bushy outside gills. These then have been added to the developmental history, but inasmuch as they have no ancestral significance they are said to

be Coenogenetic. Whilst, therefore, the development of an individual tends to recapitulate the history of the race, any attempt to reconstruct the racial history from the individual life story must make allowance for falsifications due to hastening, to skipping, and to interpolation of stages.

CHAPTER XXV

ADAPTATION AND EXTINCTION

MUCH has been written in previous pages about the living organism being a combination of independent characters or groups of characters. Each of these is not fixed, but is for ever changing both in racial history and in individual development. The emphasis has hitherto been upon independence. It must now be placed upon combination, for the living creature is not an agglomeration but an organisation of independent characters. It is like a human community, in which each person has his own life story and does his own work. Whilst one passes to old age, another grows to maturity. In all members there is unceasing change, progressive or retrogressive, slow or rapid. They are not, however, so rigidly organised that there is no room for latitude, nor are they so loosely joined that adjustment is out of the question. The early-comer waits for the late-comer ; the meeting is, therefore, effected and the joint business is transacted. The organism is a community, the community is an organism.

The individual and the race depend for their existence upon their environment. This, like the organism, though wonderful in its complexity and diversity, consists in its ultimate analysis of only a small number

of units. These are present in every age. Since living things have existed on the earth there have always been sea floor and open water, land and air. On the sea floor there have always been shore-lines washed by tides, shallow waters illuminated by sunshine, gloomy muddy depths and cold dark abysses. On the land there have always been lowland plains and swamps. These units are not constant in their position on the earth; their relative positions are shuffled about and whilst some members of a lineage move with the unit of environment they inhabit, many are overtaken by or migrate to other units. The latter must, therefore, undergo adjustment to the change in their environment and are, therefore, subject to two compelling necessities. On the one hand there is the inevitable change through which each of its characters must pass, changes of length, of septa, curvature of shell, calibre of theca, changes that are intrinsic and have in themselves no relationship to environment. The septum, for example, changes in length only by growing longer or shorter, the shell changes in curvature only by becoming straighter or more curved. Because of these changes the organism as a whole tends to undergo a certain modification of form and appearance which in itself has no special relationship to the environment. Such modification is described as *morphological*.

Modern and late Palæozoic crustacæ and early Palæozoic trilobites all live or lived, so far as evidence is available, under the same conditions of physical environment, composition, temperature and depth of water, clearness and turbidity, sunlight and gloom.

They originated in a common ancestry and yet how different they are, the one from the other! This difference is morphological.

The other compelling necessity is the need for an harmonious adjustment of the organism as a whole to its environment. If this does not exist it dies. At first sight the predetermined nature of the changes undergone by the individual characters seems to preclude the possibility of such an adjustment. This would indeed be the case if the changes which took place in one were wholly dependent upon those of another. The only change the organism could possibly undergo would then be represented thus: $K_1 L_1 M_1$, $K_2 L_2 M_2$, $K_3 L_3 M_3$. But the characters are not so rigidly related to one another. Both in evolution and development difference in speed of change exists for the same characters in different individuals and sequences of individuals. All may start at $K_1 L_1 M_1$, but in later life or in the next generation the combination may be either $K_2 L_1 M_1$ or $K_1 L_2 M_1$ or $K_1 L_1 M_2$ or $K_2 L_1 M_2$, and so on, to a great number of times. Interbreeding between these variations provides ample opportunity for the coming into existence of yet other combinations. Some of these may not be adjusted at all, some only slightly, others again almost perfectly to any changes of environment—brought about either by the migration of individuals into other districts or by earth movement or other physical causes in the district where the creatures live. Whilst, therefore, the changes in the individual characters follow a rigid and undeviating sequence, the almost infinite possibilities of differing combinations

give to a lineage of individual organisms an extraordinary plasticity. A certain proportion of the multitude of individuals may have just those combinations of character that are reasonably adjusted to the environment. These live and propagate. They are said to be adapted to their environment, and are described as adaptive modifications.

A race, during its periods of progress and acme, is continually producing such combinations and adaptive modifications. Ultimately, however, the race begins to decline, its adaptability or power of producing new combinations diminishes. A possible explanation of this may be found in two facts. The first is that the changes any one character may undergo are limited. Thus the septum of a coral can grow no longer than the space between the centre and the epitheca. At the other extreme it can do no more than disappear. The other fact is that whilst some of these changes are reversible, others are irreversible. Thus a septum may, after lengthening, begin to shorten, but if it has once disappeared it will not return. In the case of the *Gryphæa incurva* lineage, there seemed to be no slackening of the process of secreting lime and no diminishing of the curvature of the shell during evolution. As first one, and then another, of such irreversible series approaches its ultimate term, the possibilities of new combinations and therefore the adaptability of the lineage diminishes, and extinction follows.

Some races and lineages run through the whole gamut of possible combinations rapidly. Their history, like that of the graptolites and of *Gryphæa*, is short.

Others move so slowly that they seem hardly to change at all through vast periods of time. It may be that they are well adapted to a certain environment and that, whilst lands rise and sink, and shore-lines shift to and fro, they move, not out of, but with their habitat. The Brachiopod *Lingula* lives to-day in the mud that is being laid down in the Japanese sea, in the neighbourhood of estuarine waters. *Lingula* shells that differ but little from it are found in Protozoic shales. The Pearly Nautilus or Chambered Nautilus, which lives in the Pacific to-day, differs only in a slight degree from the nautiloid shells found in the rocks of the middle of the Mesozoic. These types are spoken of as short ranged and long ranged respectively. The fossil remains of the former are peculiarly valuable to the geologist as indicators of time and for correlating rocks with one another. The latter are of value to the biologist as "living fossils" or persistent types which provide an opportunity for a more complete knowledge of the anatomy of ancient forms of life than can possibly be culled from a study of fossil remains.

One special aspect of the phenomenon of adaptation should be mentioned. Hitherto, for the sake of clearness, it has been assumed that each unit of environment is occupied by only one race of organism. This is not the actual state of affairs in Nature, for every unit of environment is peopled simultaneously and in successive ages by several distinct racial types. Thus the open waters of the Protozoic seas were occupied contemporaneously by multitudes of shell-forming Protozoa, the foraminifera, by many Graptolites, and a few

Trilobites. These organisms, though so diverse, being confronted by precisely the same physical conditions, tended to become adapted in similar ways. The branches of the Graptolites were long and filamentous, (Fig. 24 b), the bodies of the Trilobites (e.g., *Acidaspis*) became covered with numerous hair-like spines (Fig. 24 a), whilst from the protoplasmic body of the Protozoa emerged clusters of thread-like processes (Fig. 24 c). Thus in each case the surface of the body was

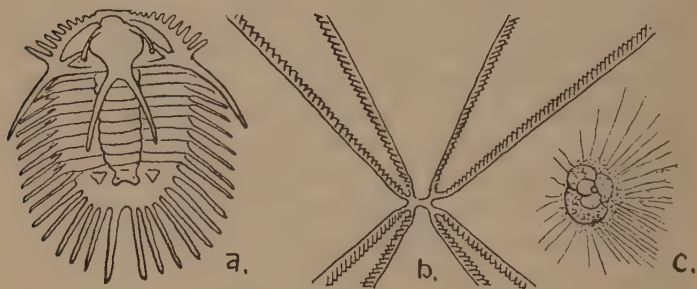


FIG. 24.—Three examples of quite different organisms which have resorted to the same device for keeping themselves afloat. a, a trilobite (*acid aspis*) ; b, a graptolite (*dichograptus*) ; c, a protozoon (*globigerina*).

greatly increased proportionately to its weight and bulk and, therefore, the creatures were kept afloat more easily in the water. This tendency for animals that are not closely related and that occupy the same unit of environment at the same period of time or in successive ages to assume similar adaptational forms is called **Convergence**.

CHAPTER XXVI

ADAPTATION TO LIFE ON LAND

WHILST all the phyla of the animal kingdom are abundantly represented in the sea, only a few have any representatives upon the land. Some of these are only very scantily represented.

A few Protozoa and worms inhabit the soil and fresh water. The large and diverse molluscan phylum is represented by that small section which includes the snails and slugs. Two phyla have, however, produced combinations of structural characters that have enabled them to live on land and breathe air with unqualified success, viz., Arthropoda and Vertebrata. As indicated by known fossils, it was not until Deutozoic times that the requisite modification of structure was attained. These facts all show that the sea was the original home of living things. Furthermore, the fact that protoplasm consists largely of water and cannot continue unless an adequate supply is forthcoming suggests that it originated in watery surroundings. In passing from the aquatic to the terrestrial mode of life there were two outstanding physical difficulties to be overcome. In water the weight of the body is supported largely or entirely by the water. Air, being much less dense than water, exerts only a slightly buoyant action

on the body. Worms, slugs and snails have avoided the issue by being content with burrowing and creeping. The Arthropods, whilst they were as yet purely aquatic animals, possessed suitable supports in the form of legs covered with a rigid shell ; for them this difficulty was therefore already solved. The Vertebrata on the other hand did not possess such supports ; true, they had limbs, but these were only flimsy structures used for guiding the movements of the fish as it swam through the water.

Nevertheless during early Deutozoic times there were some fish (Crossopterygii) that had less flimsy fins provided with a stout axis of flesh strengthened by a gristly skeleton (Fig. 25 b). It was from these fishes that terrestrial vertebrates originated, and it was this fleshy axis that provided the beginnings of legs. The first vertebrates that occupied the land merely sprawled along, with their bellies on the ground (Fig. 25 c), and their weak limbs spread out sideways. As the gristly skeleton became changed gradually to bone, these limbs became strong enough to be used for supporting the weight of the body. To this end they became bent downwards first in their middle portions, and ultimately throughout their whole length (Fig. 25 d, e). Thus the body was raised above the ground, and the problem of supporting its weight and transporting it quickly was solved.

 The second and much greater difficulty to be overcome in the passage from aquatic to terrestrial mode of life, was that of countering the loss of water by evaporation. Here again the Arthropoda had the initial advantage that the body was already enclosed in a thin, impervious covering. It is not surprising, therefore,

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that fossil evidence proves the existence of air-breathing Arthropods that could not only run about on land, but could fly whilst, as yet, the vertebrates were still in partial bondage to aquatic conditions, during later Deutozoic or Carboniferous times.

As with the problems of support and movement on land, so with the difficulties associated with the loss of water, the vertebrata overcame them as they encountered them, and therefore became adapted to

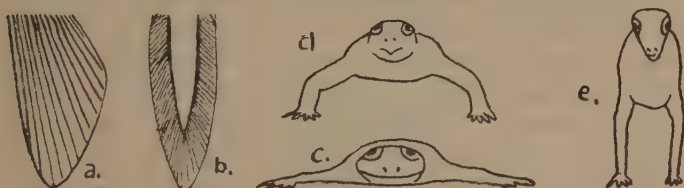


FIG. 25.—Types of vertebrate limb.

a, fish's fin wholly supported by thin horny or bony rays.

b, fish's fin (crossopterygian) with stout fleshy axis, and fringe of fine rays.

c, primitive land animal with limbs sprawling sideways, and body lying on the ground.

d, land animal in which part of each limb has bent downwards, and thus the body has been lifted above the ground.

e, land animal in which the whole limb has been turned downwards and become straightened out, with the result that the stride is longer and the body raised higher.

terrestrial conditions much more gradually than did the Arthropoda. The changes of structure that took place mainly affected the soft and perishable parts of the body. The actual details must, therefore, be inferred from the study of the various grades of living vertebrata. They cannot be learned solely from the study of the fossils. These nevertheless throw valuable light upon

the order and time of appearance of the grades. The pressure of the difficulties arising from the loss of water by evaporation is felt more especially at three points, namely, over the surface of the body as a whole, over the surface of the breathing apparatus, and over the surface of the eggs.

The danger of excessive loss from the surface of the body was the one most seriously felt in the first instance by the earliest land vertebrates. These were Amphibia, which, like frogs and newts, lived, when upon the land, in damp and swampy places. Some, however, moved into drier situations. A portion of these became the reptiles, which are represented to-day by lizards, snakes and tortoises. These retained the waste epidermal tissue that is being continually shed from the skin, as a thick, almost horny impervious covering to the body. Another portion became the Mammalia. In this case the horny covering was not continuous but grew indefinitely at innumerable points, thus producing hairs. These being closely crowded formed a covering of fur which by entangling the moist air around the body prevented excessive evaporation.

For breathing, the retention of a moist surface where the oxygen of the air could gain access to the fluids of the body was essential. The ancestral respiratory organ, the gill, of the fish, was, however, in too exposed a situation. Use was accordingly made of an internal sac akin to the swim bladder. Being within the body the passage of air over its surface was under control, and excessive evaporation was prevented. The newt and other similar Amphibia have both the external gills

and sac-like lung for a considerable portion of their lifetime. No doubt a similar dual arrangement was possessed for a while by all the earliest candidates for a terrestrial mode of life.

The problem of evaporation as it affects the egg is a much more difficult one than in the two cases just considered. It is complicated by the fact that, according to the principle of palingenesis there is imposed upon the organism the necessity for repeating some phases of its ancestral history during development.



FIG. 26.—Diagrams showing structure and relative sizes of the eggs of frog (a) and fowl (b and c). c shows the condition of the contents of a fowl's egg when the embryo is well developed.

That is to say, a terrestrial animal must for a portion of its existence be essentially aquatic in its constitution.

In the early phases of the evolution of terrestrial animals this difficulty was overcome, as is the case with frogs and newts, by laying the eggs in water (Fig. 26 a). There they hatched, and the young were in their element. Tethered thus to pools and swamps, animal life could not possibly become perfectly terrestrial. To escape from this bondage it was essential that hatching should not take place until the little being had become a typical land animal. The stages reminiscent of aquatic

ancestry must, therefore, be accomplished within the egg. That is to say, development within the egg must last much longer. This necessitated, therefore, very effective precautions against evaporation, whilst allowing access of air for the supply of oxygen. It also involved the provision of a sufficiently large supply of food material in the form of yolk (Fig. 26 b) to keep the organism nourished until it had not only hatched out but was able to forage for itself. The laying of a multitude of small eggs with small yolks gave place to the laying of only a few with large yolks. The consideration of the details of a hen's egg in this connection is very instructive.

The laying of large, well-protected eggs is one of the fundamental distinctions between reptiles and Amphibia. Among Mammalia another advance was made during the Mesozoic period. The egg, instead of being laid and left to the erratic care of physical nature, was retained within the body of the parent where all risks of exposure to such vicissitudes as sudden or extreme changes of temperature were eliminated. At first, yolk was still provided, but later the placenta, a device for transferring nourishment and oxygen from the parent to the embryo came into existence and the yolk was no longer produced.

Though these various phases of change cannot be seen in fossils, they are associated with many different structural changes even in the skeleton. These are recognisable in fossils and thus make the reconstruction of the sequence of events in terms of geological time a possibility,

CHAPTER XXVII

SPECIALISATION AMONG MAMMALS

THE remains of a number of reptiles exhibiting mammal-like peculiarities in their bones and teeth are found in rocks of early Mesozoic date in several parts of the world. The jawbones of creatures closely allied to the egg-laying and the pouched mammals that live to-day in Australia have been found in rocks of middle Mesozoic or Jurassic age. These earliest undoubted Mammalia were about the size of a rat and, as judged by their teeth, probably fed upon insects and other small forms of animal life. They were but obscure members of the land fauna, which at that time consisted mainly of reptiles showing all the diversities of size and adaptation which characterise a race in its heyday. During the late Mesozoic the reptiles waned, and at the opening of the Cainozoic they had so far declined that they were no longer the dominant element in the fauna. Meanwhile the Mammalia had emerged from their period of racial obscurity and were progressing rapidly. Fossil remains show that whilst, as yet, none were larger than a sheep, they had become adapted to many and varied modes of life. There were vegetable-eaters, flesh-eaters and insect-eaters, gnawers and tree-climbers, and others of semi-aquatic habits. With the continuance of their development through the middle Cainozoic, they reached their racial acme, and exhibited yet greater

variation in size and appearance and more perfect adaptation to differing modes of life. The ancient and archaic types had almost disappeared, and had been replaced by the forerunners of existing forms. In subsequent ages the Mammalia have experienced a slight decline.

Whilst adaptation to various modes of life does to some extent affect all parts of the body, it does not affect them equally. Some parts become so changed from the original or primitive condition that the fundamental similarity to this becomes obscured. Such highly modified parts are said to be specialised. Specialisation is exhibited more frequently and to a more marked degree by the limbs, especially the feet, and by the parts of the head, especially the teeth.

The limbs of all terrestrial vertebrates are constructed upon a common plan (Fig. 27 a to c), consisting of a long portion made up of two segments, the upper and lower limbs, hinged together at the knee and elbow; and a short flat portion, the foot, which rests upon the ground. The word foot may be used here to include the hand. This latter portion is hinged at the ankle, or the wrist, on to the long portion. It consists of a compact plate (Fig. 27 d), the sole, with five extensions along the margin called digits. In all Mammalia the first digit (Fig. 27 k), like the thumb and big toe, consists of two segments or phalanges, the remaining digits consist of three. The last phalanx has a more or less complete horny covering, the nail, claw or hoof, as the case may be. Starting from such a common plan the limbs of Mammalia become specialised in many diverse

ways. The specialised condition was attained in each case in all probability in the same gradual way during the evolution of the lineage as that described in earlier chapters. For some lines of specialisation the fossil evidence for this approaches completeness (Fig. 27, e to h), for others it is not, as yet, forthcoming.

Specialisation for the fleetness of foot is expressed by further elongation, especially of the lower limb. Additional length of limb is also gained by raising the sole off the ground (Fig. 27 a, to c), and then subjecting

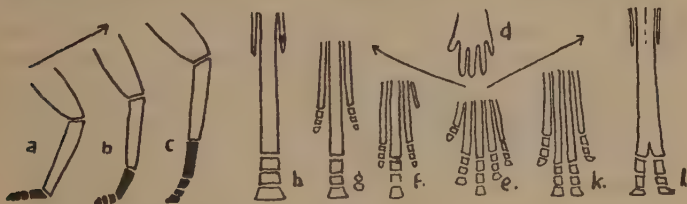


FIG. 27.—Diagrams showing the main modifications experienced by the limbs of running mammals.

a to c shows how the leg is elongated by the addition to its length first of sole (black) and then of the digit (black).

d, plan of a primitive hand.

e to h shows the changes leading up to the condition in the horse.

e, k, and l shows the changes leading up to the condition in the sheep.

it also to elongation. The portions of the digits then rise in succession (Fig. 27 e to h, e, k, l).

Eventually only the tips of the longest digits rest upon the ground, and they become thickened whilst the remainder degenerate and disappear. The limbs of horses and cattle provide examples of this mode of specialisation. A very different line of specialisation

is exhibited by mammals that adopt aquatic habits. In these the rod-like portion of limbs shortens (e.g. otter and hippopotamus). In wholly aquatic types such as seals and whales this shortening is carried still further, whilst the foot becomes relatively much larger and more expanded. At the same time the hinge joints between the segments stiffen and the limb as a whole becomes a rigid paddle or flipper. In specialisation for flight (e.g., bats) the phalanges lengthen, the digits of the front foot become enormously elongated like the ribs of an umbrella and form a framework to support a large portion of the broad expanse of skin which is used as a wing. Other not less interesting specialisation of the limbs occur, but these will suffice to illustrate the great diversity which may arise out of a common basis of a few independent structural units.

Teeth are not less subject to adaptive changes than are the limbs and feet. Moreover, they resist the disintegrating influences of Nature more effectively, perhaps, than any other portion of the body, and on that account are frequently preserved as fossils when all other parts have disappeared. In fishes and Amphibia (Fig. 28 a) they are usually small and numerous, and may grow on almost any part of the lining surface of the mouth. In reptiles (Fig. 28 b) they are larger, fewer, and usually confined to the margin of the mouth. Their form is still that of a simple cone, as it was in the lower vertebrates. In Mammalia (Fig. 28 c), however, the number has become greatly reduced—so much so that it does not usually exceed 44. On the other hand, they exhibit a diversity of form that is approached only

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among certain mammal-like reptiles that lived in early Mesozoic times. All these features may be seen typically exemplified in a dog. Attention may be confined to one side of either the upper or the lower jaw. In front are three chisel-like teeth, the incisors. Behind these is one large tooth, the canine, which has the simple conical form of the reptilian tooth. The remainder, the cheek teeth, are grouped into four premolars in front, and three molars behind.

A typical mammalian tooth has a hard, enamel-covered crown, which is raised above the gum, and a



FIG. 28.—Lower jaws, and typical teeth of various land vertebrata. a to c, lower jaws ; a, amphibian ; b, reptile ; c, mammal.

d, upper and lower cheek teeth of carnivorous mammal, showing the way in which the sharp edges pass one another like the blades of a pair of scissors.

e, upper and lower cheek teeth of mammal that feeds upon soft succulent vegetation, showing the way in which the crowns meet for crushing food.

f, lower cheek tooth, showing the greatly deepened crown. This allows for prolonged use in the process of grinding dry vegetation.

g, lower cheek tooth of elephant.

root consisting of one, two, or three fangs which are embedded in the gum.

The cheek teeth, especially the molars, are the ones which exhibit the greatest variety of adaptive modifications. In dogs and cats and other flesh-eating mammals

the crown is slightly elongated from back to front, and raised into a sharp irregular ridge. When the mouth closes the ridges of the upper and lower teeth pass one another like the blades of a pair of scissors (Fig. 28 d), and are, therefore, well arranged for slicing lumps of meat off a joint or a carcass. In a pig (Fig. 28 e) on the other hand, the top surface of the crown is roughly tabular and marked by low, blunt lumps or cusps. The corresponding surfaces of upper and lower teeth come together and serve the purpose of pounding soft vegetable food. In horses, cattle and sheep (Fig. 28 f) the cusps have become enormously increased in height, and the valleys between have been partially filled with cement. The crown has thereby become very tall or deep. In these cases the natural food was not succulent herbage but dry grass, which had to be ground rather than pounded. The upper and lower teeth move over one another with a grinding motion, and in doing so they become worn away. As each cusp in this deep crown consists of a bony substance called dentine, coated with enamel, and is surrounded by cement, the crown as a whole is a complex of three materials having different hardnesses. These naturally wear away at different rates, with the result that the grinding surface remains rough throughout life. In these cases the teeth are all in use simultaneously. In the elephant (Fig. 28 g), however, this is not so, but a further adaptation is brought about. Only one, or at the most, two, teeth are in use at the same time on each side in the upper and lower jaws respectively. These are of enormous size and have very deep crowns. When one tooth is

nearly worn down another comes into action from behind and gradually replaces it.

In all the above cases, each tooth when fully formed ceases to grow, but in rabbits and other rodents each tooth grows continuously throughout life, and thus the loss by wearing down is counter-balanced. Other equally interesting specialisations of teeth also occur. In every case where adequate fossil evidence is forthcoming, even the most specialised are found to have developed from a simple primitive type of tooth. The fact that these varying types of specialised limb and tooth have been derived from primitive non-specialised structures shows that the latter are very adaptable. That is to say, they are capable of producing many variations, or combinations of their structural units, in different stages of development. On the other hand, specialisation is accompanied by the elimination of those combinations less suited to the particular mode of life. Thus specialisation for speed is accompanied by the elimination of the other digits. Again deep, flat-crowned teeth and sharp, cutting edges are mutually exclusive modifications. The evidence from fossils proves that it is those creatures in which there is the greatest number of structural units at an early stage of their developmental history that become the starting point of new races. Such primitive organisms become the radicles for new types. On the other hand specialised organisms being unable to produce new structural combinations that may fit the new conditions of a changing environment, are the last terms of racial series and precede extinction.

CHAPTER XXVIII

THE EMERGENCE OF MANKIND

MAN is not above, but is a part of Nature. He must, therefore, have a place in any systematic classification of natural objects. This can only be discovered by comparing his physical structure with that of other living things. When this is done it is found necessary to classify him with the animals rather than with the plants, with the Vertebrates rather than the Arthropods, Mollusca, or other phyla of the animal kingdom. Such facts as that his young are born alive and are suckled, that his body is more or less covered with hair, that four of his digits each consist of three phalanges, that his teeth are few and varied in form and pattern, together with a multitude of other facts, show that he must be classed with the Mammalia.

The most careful investigations conducted by highly skilled anatomists have failed to reveal in him any important structural unit that is not possessed by other mammalia. The difference between him and them, therefore, is in the combination of developmental stages of those units. The outstanding differences may be best realised by comparing him with his companion the dog. The dog stands on all four legs and rests on its digits. Man stands on the hind pair of limbs with the

whole length of sole as well as of digits resting upon the ground. His body is erect and not horizontal, and his front limbs are thus freed from the necessity of functioning as legs. These arms, as they are called, swing freely in all directions, and do not have their upper portions bound to the side of the chest, as in the dog, in which they can execute only a backward and forward movement. In association with this he has a broad chest and shoulders, which are in marked contrast with those of the dog. His hands have all digits well developed, the first being opposable to the others, and the

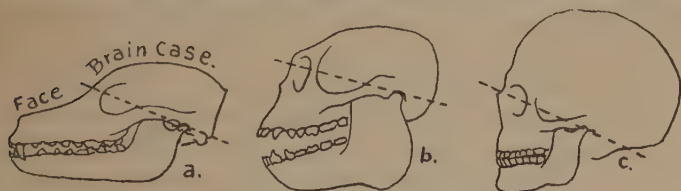


FIG. 29.—Diagrammatic side views of skulls : dog, a ; monkey, b ; man, c ; showing relative development of face (below the line) and brain case (above the line).

horny structure on the last phalanx is a broad flat nail, and not a narrow hooked claw.

Striking as these differences are, still more striking are those which are found in the head. Thinking of this as consisting of two main regions, the face and the brain case, it is seen that in the dog (Fig. 29 a), the former predominates, projecting far in front of the brain case to form what is called the muzzle. In man (Fig. 29 c) on the other hand, the face is greatly shortened from back to front, and is subordinated to the brain case, which partly overlies it. In man the eyes

face forwards with their axes parallel. In the dog they face more or less sideways, with their axes diverging. The teeth also show a marked difference in number, shapes and arrangement. On each side of each jaw in man there are two incisors, one canine, two premolars and three molars ; their crowns are of uniform height, and those of the cheek teeth are low and flat. For the dog, the corresponding numbers are 3, 1, 4, 3, their crowns are of varied height, and the cheek teeth have sharp-edged crowns. Looking at the general arrangement of the teeth as a whole in the lower or upper jaw, that in man is almost a semi-circle, in the dog a long, hair-pin shaped arch.

These same features which distinguish man from the dog distinguish him from all other orders of Mammalia except the apes and monkeys. These animals also differ from the other Mammalia in these same respects, but to a slightly less marked degree. Thus, for example, in these creatures (Fig. 29 b) the brain case is large but, relatively to the face, is smaller than in man ; and there is a slight muzzle. Again, though the monkey runs on all fours, it often assumes an erect attitude of body ; its first digit is opposable to the others, and the terminal phalanges bear nails. Its arms swing freely in all directions, and the chest is broad.

Its teeth usually number 2, 1, 2, 3, and their appearance and arrangement closely resemble those in man. Among the apes the degrees of difference from man diminish. At the other extreme, among the lemurs, they become much more marked. These little creatures at first sight look very much like ordinary four-footed

mammalia. Nevertheless, they differ from^r these in the same way but to a much smaller degree than do the monkeys. Thus, for example, their brains are larger and their eyes face forwards. Again, whilst some of their digits have claws, others have nails.

Such facts are illustrative of a large body of facts which justify the classification of man with the apes, the monkeys, and the lemurs in the order Primates, in which the predominant line of specialisation which distinguishes them from all other orders of Mammalia is the enlargement of the brain. With this are associated a number of other modifications, such, for example, as the reduction of the muzzle and of the number of teeth, the freedom and mobility of arms and digits. The enlargement of the brain reflects a great advance in intelligence and alertness. This, together with their predominantly arboreal, or tree-climbing habits, rendered the primates less liable to be caught by floods or overwhelmed by other catastrophes which might lead to their burial and preservation in the fossil state. The record of their evolution is therefore very fragmentary as compared with that already discovered and elucidated for the horses, elephants, and other Mammalia. Nevertheless, sufficient evidence is forthcoming to show that the sequence of changes in time accord with grades suggested by the study of the lemurs, monkeys and apes respectively.

The Cainozoic period is subdivided into five divisions, viz., Eocene, Oligocene, Miocene, Pliocene and Pleistocene. Lemurs already existed in early Eocene times. Monkeys appeared during the late Eocene. The

earliest ape recorded is *Propliopithecus* from the Oligocene deposits of Egypt. The Gibbon which lives to-day in the forest of south-eastern Asia and the Malay Archipelago most nearly preserves the appearance and characteristics of this ancient and primitive ape. The chimpanzee, gorilla and orang-utan have each undergone further specialisation in directions diverging from that shown by man. Thus, for example, in the hind feet the first digit or toe is like a thumb opposable to the other digits, a valuable asset for an arboreal creature. Apes are the highest primates whose remains have been found in rocks of Miocene age. Traces of creatures belonging to the human rather than the ape or anthropoid lineage have been found in the pliocene, but these are limited to teeth. It is not until the close of the Pliocene, or the opening of the Pleistocene, that more ample fossil remains of man-like creatures have been found of sufficient completeness to provide a picture of his appearance. These occurred in certain deposits in Java, and consisted of the skull cap, part of the lower jaw, three teeth and a thigh bone. The skull cap indicated a brain larger than that of the largest ape, but slightly smaller than that of the smallest human brain known. This, with other characters, shows that it could not strictly be classified either with man or with the apes, a fact which is reflected in the scientific name that has been given to it, viz., *Pithecanthropus erectus*.

During the passage of the Pliocene period a gradual change in the general character of the faunas of north-west Europe took place. This consisted of a steady

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decrease in the number of southern forms and a corresponding increase of northern forms, a fact which indicated that the climate was becoming progressively cooler. Eventually it became so cold that extensive icefields became established in that region, and the alpine glaciers crept down the valleys to levels several thousands of feet below the present snowline. Those portions of Europe that were not covered experienced at the same time climates of subarctic severity. This period of glaciation was followed by an amelioration of climate which then became slightly warmer and more genial even than it is at the present day. This sequence of events was subsequently repeated three times. During this so-called Ice Age or Pleistocene period there appear to have been four such cycles of glaciation, separated by long genial interglacial periods.

It was whilst these events were taking place that, as indicated by the evidence at present available, mankind advanced from a stage in which he was not far removed from the status of a primitive ape to one in which he was but little lower than his modern highly cultured and civilised descendants. For the same reason as those already indicated for primates generally, the fossil remains of early man are rare and often very fragmentary. The earliest hitherto found is one tooth from the Pliocene. More complete remains come from deposits formed before the middle of the Ice Age. They include those of Java man and Piltdown man. In the former the brain case had the capacity (expressed in cubic centimetres) of from 850cc.—900cc., or about 250cc.—300cc. greater than that of the largest ape known. Like

an ape, however, it had strongly marked brow ridges and a rapidly receding forehead, which was pinched in at the sides behind the orbits. The Piltdown skull was found in certain ancient gravels resting on the plateau surface of the Downs in Sussex. It had a capacity of 1100cc. As in modern man the brow ridges were not prominent, the forehead did not recede rapidly, but was smooth and round, nor was it markedly pinched in at the sides. Nevertheless, it had a projecting ape-like face, with a receding chin and prominent canine teeth. Whilst, taking all characters into account, both these creatures must be classed with men rather than with apes, they are sufficiently different from one another and from modern man to merit not merely different specific but even different generic names. Present-day men, of all races, are called *Homo sapiens* ; but Java man is called *Pithecanthropus erectus* ; and Piltdown man, *Eoanthropus dawsoni*. More numerous remains have been found in deposits apparently contemporaneous with the last interglacial period and the first half of the fourth cycle of glaciation. The discovery of these is due to the fact that man at this time frequently buried his dead. These interments were sometimes made in caves where the earth that slowly accumulated on the floor was protected from the destructive action of atmospheric and other geological agencies. These remains have so many peculiar features in common with one another that they are all regarded, in the present state of knowledge, as belonging to the same race, the Neanderthal race, so named after one of the sites where skeletal remains have been found.

Neanderthal man was of uniformly small stature with an average height of only five feet two inches. The backbone or vertebral column had not the forward curvature in the lumbar region seen in modern man, but the "bent back" curvature of a baby or of an ape. This, together with indications of a slight bend at the knees, shows that he walked with a stooping or slouching gait. His arms were relatively long, and the lower parts of the leg were relatively short. This latter fact indicates that he was not very fleet of foot. Both hands and feet were large. The neck was thick and carried the head thrown slightly forward.

The head was large and had a cranial capacity ranging from 1100cc. in some individuals to 1600cc. in others. In this respect it was quite equal to the capacity found in any modern man. The shape of the brain case was, however, peculiar in that it was much wider in proportion to its height. This imparted to the cranium a flattened form with bulging sides. It, therefore, presented, in these respects, a marked contrast to all subsequent human races, in which the cranium is elevated, and has its sides rising vertically like the walls of a house.

The prominent brow ridges, and rapidly receding forehead, pinched in behind the orbits, recall the conditions in *Pithecanthropus*. Notwithstanding the large size of the brain case, the face projected like that of the ape, which it resembled in other features also. Thus, for example, the sides of the nose sloped gradually and merged into the cheek without showing any definite boundary between these two portions of the face.

Again, the front end of the jaw showed no signs of the chin, which is a feature that is so distinctively human ; on the contrary, it receded as it does in apes and monkeys and all the other Mammalia.

Whilst, taken as a whole, the structural features of Neanderthal man sufficiently resemble those of the modern races to justify referring him to the same genus *Homo*, they differ markedly enough to indicate that he belonged not to the same lineage as *Homo sapiens*, but to some lineage which diverged from the main line of descent at an early date. This race is therefore referred to another species called *Homo neanderthalensis*. This species disappeared from Western Europe when the retreat of the last glaciation set in. It is believed that it became extinct, and is unrepresented among living races of mankind. The contrast between this ancient race, together with those which preceded it on the one hand, and all those which succeeded it, including living races, on the other, is so great that they are classed in two groups, called the Palæanthropic or ancient men and the Neanthropic or new men respectively. The next chapter will deal mainly with the Neanthropic races and their achievements.

CHAPTER XXIX

THE GROWTH OF INTELLIGENCE AND CULTURE

THE outstanding specialisation which characterises man is the great development of his brain not merely in size but also in complexity. There is no other part of the body that has such an intimate association with all the other parts as the brain, for it co-ordinates and controls the functions and movements of them all. Only in so far as changes in the one were accompanied by suitable changes in the other did the resulting structural combination fit the environment. In the case of the Primates the adjustment of the body to the circumstances of the habitat in which they lived was secured by an increased complexity of movements. The majority of Mammalia lived upon an extended but continuous surface called the ground, where walking and running on all fours met the needs of the situation. As long as the limbs could move freely to and fro in the same plane it was an advantage for them to be bound firmly to the sides of the body in such a manner as to prevent lateral movement. As the digits of both fore and hind feet were concerned in the support of the body, they, too, became either closely bound together to act as a mere continuation of the limb, or became reduced

in number but increased in calibre as in horses and cattle.

The forerunners of the Primates that wandered from the ground to the trees entered a habitat where the surface upon which they moved was as complex as the ground was simple, it was tilted at all angles from the horizontal to the vertical, it ran off along branches in narrowing strips which ended in thin and flimsy supports. The animal that made its way along these narrow strips had either to maintain its balance, and turn round in very limited spaces, or to leap from bough to bough, or to fall.

In some arboreal animals belonging to other groups of mammalia these conditions were met by the appearance of a structural combination that reduced all risks to a minimum. In the sloth powerful claws came into being. These enabled the creature to hang from the boughs and move only slowly from point to point. In others, e.g., flying fox, the risks of falling were met by another combination, involving a sheet-like extension of the skin, which, functioning like a parachute, slowed down the rate of falling to a reasonable degree of safety. Out of this combination wings arose, and the fore-limbs became involved as organs of flight. In Primates the risks were met by increased agility based upon a structural combination of limbs that were so loosely attached to the body that they could swing round and outwards as well as backwards and forwards, digits that could be opposed to one another in such a way that both hands and feet could be used for grasping. With one hand one bough could be held, whilst the free hand

stretched forth to grasp the next. In this structural combination the number of parts was kept at its full complement, and their possibilities of independent and co-ordinated movement increased to a maximum. This increase of complexity in function and movement was necessarily accompanied by a corresponding change in the brain. To what extent this correlative advance in all parts of the body was due to selection of fortuitous combinations, or to the reaction of organs to one another, and to environment, or to a happy combination of both these influences, is too speculative a problem to be discussed here. The main purpose has been served if it be realised that among natural habitats, the arboreal is the one which provided the most favourable circumstances for specialisation of the brain.

Another fascinating aspect of the question of advancing mentality is the influence of the growing relationship between parent and offspring. In Mammalia this is more intimate than in the reptiles, and there is a corresponding development of the brain. The lengthening of childhood with its longer opportunities for the young animal to become expert in life's complicated activities must also have had its share in favouring the growth of intelligence. But this digression leads off into realms that will be dealt with more fully and efficiently in books on psychology.

Returning once more to the physical aspect of these studies, it is evident that, whilst large sections of the Primates remained in arboreal surroundings, others returned to the ground. Among these were the immediate forerunners of mankind already discussed.

They returned with an organisation that was as well fitted for an upright as for any other attitude of body. The hind feet, retaining as they did the primitive structure and plantigrade condition, provided a sufficiently broad basis for an animal, expert in balancing, to stand upon. The hands, accustomed to grasping boughs, could equally well hold sticks and stones either for support or protection. Thus were the physical requirements provided which made the holding, making and improving tools and, in association with that, further advance in intelligence a possibility.

Sticks rot and perish, but stones may last for ages. The stones that the successive races of man and his predecessors handled, and even shaped, are all in existence somewhere. Those stones that were merely picked up, used as they were, and then cast away, cannot, of course, be distinguished from other stones. Those which he endeavoured to shape for his own ends may be recognised, for, just as each of the agencies that works in Nature—the rivers or glaciers, rain or frosts, volcanoes or seas—has its own peculiar way of working that enables the expert to detect its handiwork, so is it with the craftsmanship of early man. Though at first he may merely have knocked chips off his stones as indiscriminately as the frost, or the pebbles that hit one another upon the beach, he eventually developed a technique of his own which no other agency in Nature can ever systematically imitate.

Stones that have been chipped indiscriminately by him in the early stages of his dawning intelligence no doubt lie about in great numbers somewhere. Whilst

the investigator may pick up likely samples and speculate upon the possibility of human workmanship, he can as yet do no more than speculate. Apart from these, however, there are hidden away in the gravels and soils of the countryside ample stores of stones exhibiting undoubted signs of human workmanship. By the collection and study of these it has been possible to spell out the story of man's growing skill and intelligence across the ages. About the early pages of that story some uncertainty necessarily prevails. Stones having forms and chippings ascribed by some to the hands of man have been found in Pliocene and early Pleistocene, and even in Miocene deposits. These are called *Eoliths*.

In later deposits, chiefly gravels, stones which usually consist of flint have been found which have undoubtedly been shaped systematically to certain favourite forms. These are called *Palæoliths*. These deposits date from some indefinite time during the first half of the Pleistocene until the completion of the recession of the last glaciation. This period of time, during which implements of this type were being made, is called the Palæolithic or Old Stone Age. Samples of some of the earliest palæoliths were found in the gravels from which the bones of Piltdown men were obtained. In these the chipping was coarse and crude, and the cutting edges rough and irregular. Later, and with advancing skill, the edge was retrimmed and straightened, small chips being flaked off by pressure. At this stage man used flints of any shape and by process of hacking reduced them to the size he wanted. From this core, by careful

chipping, he produced a tool of the precise form required. Each flint thus used, however, yielded only one tool. Hitherto no actual remains of man himself have been found associated with implements of this grade.

Neanderthal man lived at a slightly later time, and seem to have employed a much improved technique, for he appears to have produced a number of implements from one block of flints. This he did by trimming the

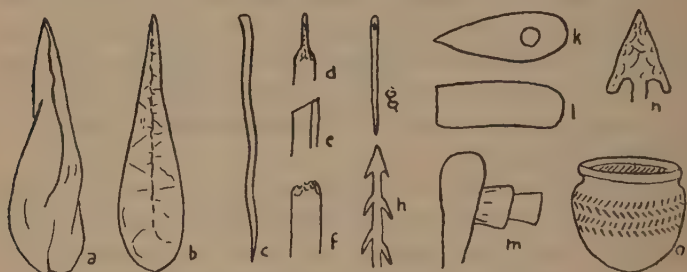


FIG. 30.—Handiwork done at different prehistoric culture stages. a to h, palæolithic ; k to o, neolithic.

a to c, diagrams showing stone implements in side view.

a, lower palæolithic, early form ; b, lower palæolithic, late form ; c, upper palæolithic showing slender character of flakes.

d to h, upper palæolithic ; d, flint borer ; e, flint chisel ; f, flint scraper ; g, bone needle ; h, bone harpoon.

k, polished stone axe with hole bore through it ; l, side view of same axe ; m, small stone axe embedded in bone and hafted on to a stick ; n, flint arrow head ; o, decorated pottery made by hand without wheel—note absence of handles and base.

surface of one end of the block, and then by one strong blow he detached this end. The large flake thus removed had one surface chipped, the other smooth, and its cutting edge was very sharp. The differences between these earlier grades of culture and those which

followed are so great that the Palæolithic period is divided into lower and upper divisions. The Lower Palæolithic was much longer, for it lasted until the retreat of the icefields of the last glaciation had begun.

Upper Palæolithic man was much more highly skilled in the art of using flint than was Neanderthal man and his predecessors. His chief accomplishment was that he could knock off long narrow flakes. These he shaped into a much greater variety of implements and tools than were ever devised by lower Palæolithic man. Knives, scrapers, borers, carvers—these are some of the names used for describing his tools. He also discovered the value of bone. Out of this, with the aid of his flint tools, he made needles, harpoons, javelin heads, javelin throwers. He also possessed wonderful artistic skill, for he decorated his bone instruments with carvings and drawings, and the walls of his cave with paintings of various objects of the chase. In Spain he went further and depicted men and women engaged in various occupations, including hunting and dancing.

With the passing away of the Ice Age came the dawn of recent times, and the appearance of a new stage of culture, the Neolithic. Hitherto flint had been the favourite stone used, because its response to a blow could be accurately gauged. It was now found that other kinds of stone could be shaped to the required form by grinding. Whilst, therefore, flint was still used and chipped, other kinds of stone were also used, but they were ground. Bone continued to play an important part as a material for making tools. Growing intelligence now found expression in agriculture; in

the domestication of the dog, horse, cow, sheep and pig ; and in industrial occupations such as weaving, and the making of pottery.

With the approach to historic times, man discovered metals. The first to be found were gold and copper, for both occur in the natural state in Nature. Then came the discovery of the art of abstracting tin and copper from ores, and of making a mixture of the two called bronze. Thus was ushered in the Bronze Age. During early historic times iron was discovered, and so the Iron Age began.

In thinking of these successive stages of culture which reflect the growing intelligence of man, it should be remembered that new cultures, like new types of organisms, did not spring up spontaneously everywhere at the same time, but they originated in one area and spread thence. Thus different cultural stages co-existed at the same time in various regions. The bronze age of the Eastern Mediterranean, for instance, antedated that of Western Europe by nearly a thousand years.

With this rapid survey of the cultural stages through which man has passed in mind, the study of the physical characteristics of man himself may be resumed.

CHAPTER XXX

HOMO SAPIENS

THE striking and sudden change in culture in Western Europe which is expressed by the separation of the upper from the lower Palæolithic was accompanied by the disappearance of Neanderthal man, and by the entry into this region of races of men who so nearly resembled modern types that they are regarded as belonging to the same species, viz., *Homo sapiens*. Whence these races came is unknown, but the routes along which later comers have travelled as they have spread not only into Europe, but also into other regions, point backwards into North Africa and South-West Asia in such a manner as to suggest that the ancestral home of mankind was situated there, that there he evolved from stage to stage. From thence successive migratory hordes went forth, across the world, taking their cultures with them, halting now here, now there, and changing as they went. Representatives of a few of these arrived by devious routes in Western Europe, where the investigation of prehistoric remains has been carried on for a longer period and with more ample results than elsewhere.

As the icefields of the last glaciation shrank, on the one hand, into the mountain recesses of the Alps ; and on the other from off the British Isles, and across the

North Sea, and from off Denmark and the North German plains across the Baltic to Scandinavia, several new races entered and replaced *Homo neanderthalensis*. As with this departed type, and indeed all subsequent types, our knowledge of their physical characteristics has been gained largely because they interred their dead often in caves or in artificially protected situations.

The most striking among these newcomers was the Cro-Magnon type, a tall, fine race, having an average stature of six feet one inch. Some even attained a height of six feet four inches. The neck, the vertebral column, the legs, all indicate that Cro-Magnon man carried himself as erectly as existing races. His arms were relatively short, and his shanks long. The bones of the latter show peculiarities of form which are associated with extraordinary fleetness of foot. This must have been a great advantage to him, for though he got his living by hunting he had not yet, so far as is known, tamed either the horse or the dog.

In the study of the crania of human beings, especially those belonging to the species *Homo sapiens*, the differences which distinguish one race from another are frequently so slight that they can be adequately appreciated only when expressed in terms of careful measurement. Among these, much importance is attached to those which show the relationship between the length, width and height of the cranium. The length is measured from the middle point between the brow ridges to the most backwardly projecting point, which lies just above the nape of the neck. This measurement, whatever its amount, is taken as a hundred. The other

HOMO SAPIENS

measurements are expressed as fractions of this, and thus give the width and height as percentages of the length. The percentage relationship of width to length is called the *cephalic index*. When this is below 75 the skull is a long one, and is described as being dolichocephalic. When it is above 80, it is said to be broad

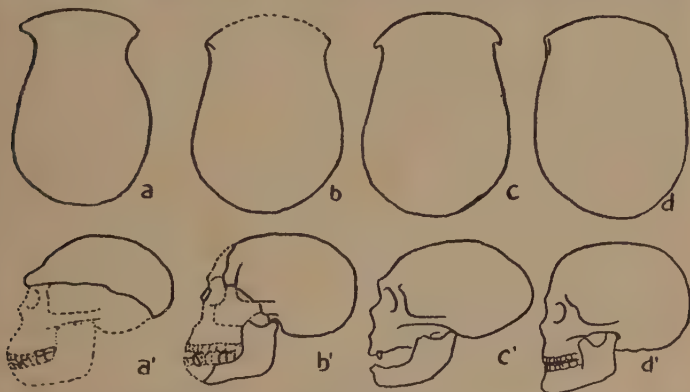


FIG. 31.—Skulls of four prehistoric races.

a to d, view of cranium or skull caps seen from above ; note the varying degrees of expansion of the front part of the cranium, in association with the degrees of development of the front part of the brain.

a¹ to d¹, side view of skull and face ; note the varying degrees of brow development and of swelling of the forehead in association with development of the front of brain. Note also degree of prominence of the muzzle or face.

a, a¹, Java man (*Pithecanthropus*) ; b, b¹, Piltdown man (*Eoanthropus*) ; c, c¹, Neanderthal man (*Homo neanderthalensis*) ; d, d¹, Cro-Magnon man (*Homo sapiens*), one of the upper palæolithic races.

and is brachycephalic. When the percentage lies between 75 and 80 the skull is of medium length, and is described as mesaticephalic. This latter term may

however, be dropped and the boundary between long and short-headed types may be taken at 78.

Returning, after the above digression, to the consideration of Cro-Magnon man, the head may now be described. The brain case was large, and had a capacity of as much as 1590cc. It was dolichocephalic for its cephalic index was 73.8. The brow ridges were not prominent, and the front portion of the cranium was well filled out, with the result that the forehead rose rapidly and was not pinched in behind the orbits. The sides of the cranium were flat and vertical. The face, unlike the cranium, was broad in proportion to its length. This combination of a short face with a long head is described as disharmonic. The nose was well differentiated from the cheeks, and was long and narrow. The face did not project, and the lower jaw possessed a well marked chin. Taken as a whole, the head of Cro-Magnon man was strikingly modern in its aspect.

One feature which distinguished this race from contemporary races was that the vault of the cranium was low, thus giving the appearance of a flat-headed type. In the Combe Capelle race the cranium was high. The face, like the cranium, was long in proportion to the width, a condition which is described as harmonic. It is believed that representatives of both the Combe Capelle and the Cro-Magnon type still survive, those of the former in Central Wales, the latter in the Cevennes region.

A third of these contemporary races is called the Grimaldi type, remains of which have been found in the caves of the South of France. This race was more

closely related to Combe Capelle than to Cro-Magnon man. As in that the stature was low, the cranium was high ridged, the nose was broad and the upper jaw projected. It was distinguished, however, by a stronger projection of the jaw and by a short face. It has been suggested that this type also survives in some of the cities in Southern Europe.

The Chancelade type was tall. The head was dolichocephalic, had a high vaulted cranium, and the nose was very narrow. There are marked resemblances between the head of this type and that of the Eskimo. Such, then, were the races of men that occupied Western Europe during the various phases in the recession of the ice-sheets and glaciers. The climate at this time was cold, and the country that was unoccupied by ice resembled in its physical conditions, vegetation, and fauna, the tundras and cold steppes of to-day. Man was then a hunter, and the chief victims of the chase were the mammoth and the reindeer. The former is now extinct, the latter still exists in herds in Lapland.

By the time that the icefields and glaciers had shrunk to approximately their present proportions in Switzerland and Scandinavia, the climate of Europe had also become similar to that which prevails to-day. It was sufficiently moist and mild for forests of pine and birch, oak, beech and walnut to grow up and spread over the open hunting ground of earlier times. The woodland stag now replaced the reindeer in the chase.

Meanwhile, three streams of migrants flowed into and across Europe, gradually absorbing or replacing their upper palæolithic predecessors. From these streams

have been derived practically all the peoples which inhabit this continent to-day. One stream entered by the south from Africa and gave rise to the modern Mediterranean races. As judged partly by skeletal remains, and partly by their living representatives, they were men of medium stature, with long cranium, moderately narrow nose, black wavy hair and tawny white complexion, sometimes darker, sometimes lighter.

This stream probably originated in North Africa. In Egypt it produced the early Egyptian peoples. Spreading westwards along the northern border of Africa they crossed the narrow seas into South Italy and Spain. The latter spread northwards through Western France, and eventually entered Britain. To this section belongs the Iberian. They also spread eastwards along the coastlands of Southern Europe, where they developed the characteristics of the Mediterranean race to the full. A second stream of long-headed people, which also originated in North Africa, migrated in a north-easterly direction, and entered Central Asia. They were of tall stature, and eventually came westwards from the steppes of Asia and Eastern Europe. Spreading over Scandinavia and North Germany, they came to the shores of the North Sea, and, crossing this, entered Britain at many points on the East Coast. The movements of this stream still continued far into historic times and contributed largely to that turmoil which is so characteristic of English history in the early centuries of the Christian era. The present-day representatives of these people are spoken of as belonging to the Nordic

Race. In them the cranium is not quite so long as in their prehistoric forerunners. The nose is straight and narrow, the skin fair, the eyes blue or grey and the hair light, wavy or even curly.

The Nordic race occupies the plains and low plateaux lying north of the mountain belt which crosses Central Europe. The Mediterranean race, on the other hand, occupies the region south of this belt, and around the western end of the Mediterranean Sea. The differences between the two have been ascribed to the influence of the climatic conditions under which they have now lived for many generations. In the more genial south, sex maturity is attained earlier, and the growth period has been limited accordingly, with the result that the physical framework with its clothing of muscles tends to be small rather than massive. The sunny climate has its counterpart in a slight darkening of the skin.

In the less genial north, the sex maturity comes later, the growth period is correspondingly longer and the body has become larger and more massive. In association with the more cloudy skies there is an absence of pigment in the skin.

Beyond the western end of the mountain belt the regions occupied by these two races merge into one another, and pass into the British Isles. Here the two races intermingle, and every grade between the extremes is found in the population.

The third stream, the predecessors of the Alpine races, originated in the plateaux and highlands of Western Asia. Entering Europe, they still kept to their native habitat, moving along the mountain belt from

the Balkan peninsula westwards. This race of short-headed people came rather later than did the long-headed races. The latter, as shown above, occupied Western Europe throughout Upper Palæolithic times. But it was not until the closing portion of this period that the forerunners of the Alpines appeared upon the scene. The remains of these have been found in caves at Ofnet in South Germany and Furfooz in Belgium.

During Neolithic times this Alpine race gained a firm hold upon the fastnesses and forested slopes of the European mountain belt. They were the people who built their dwellings on piles out on the lakes. With them they brought the Neolithic culture. They practised agriculture, and cultivated wheat, barley, millet, and flax. They also brought domesticated animals and pottery.

During the Bronze Age they penetrated Britain. The traces of their presence are revealed by the contents of the round barrows or burial mounds. They did not, however, leave any marked effect upon the population of these islands, which is predominantly dolichocephalic.

These three streams of migrating folk furnish the basis out of which the present population of Europe and the British Isles has grown. Where these streams adjoin one another or unite, peaceful intermingling has taken place, and other sub-racial types have been produced. Some of these, like the Beaker folk and the Celts, have migrated from their place of origin and left their impress upon the population of regions beyond, including Great Britain. Others again have remained comparatively stationary and have thus added their quota to the patchwork of peoples that to-day occupy Europe.

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